

PROJECTS THEORY APPLICATIONS CIRCUITS TECHNOLOGY

NUTS
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VOLTS

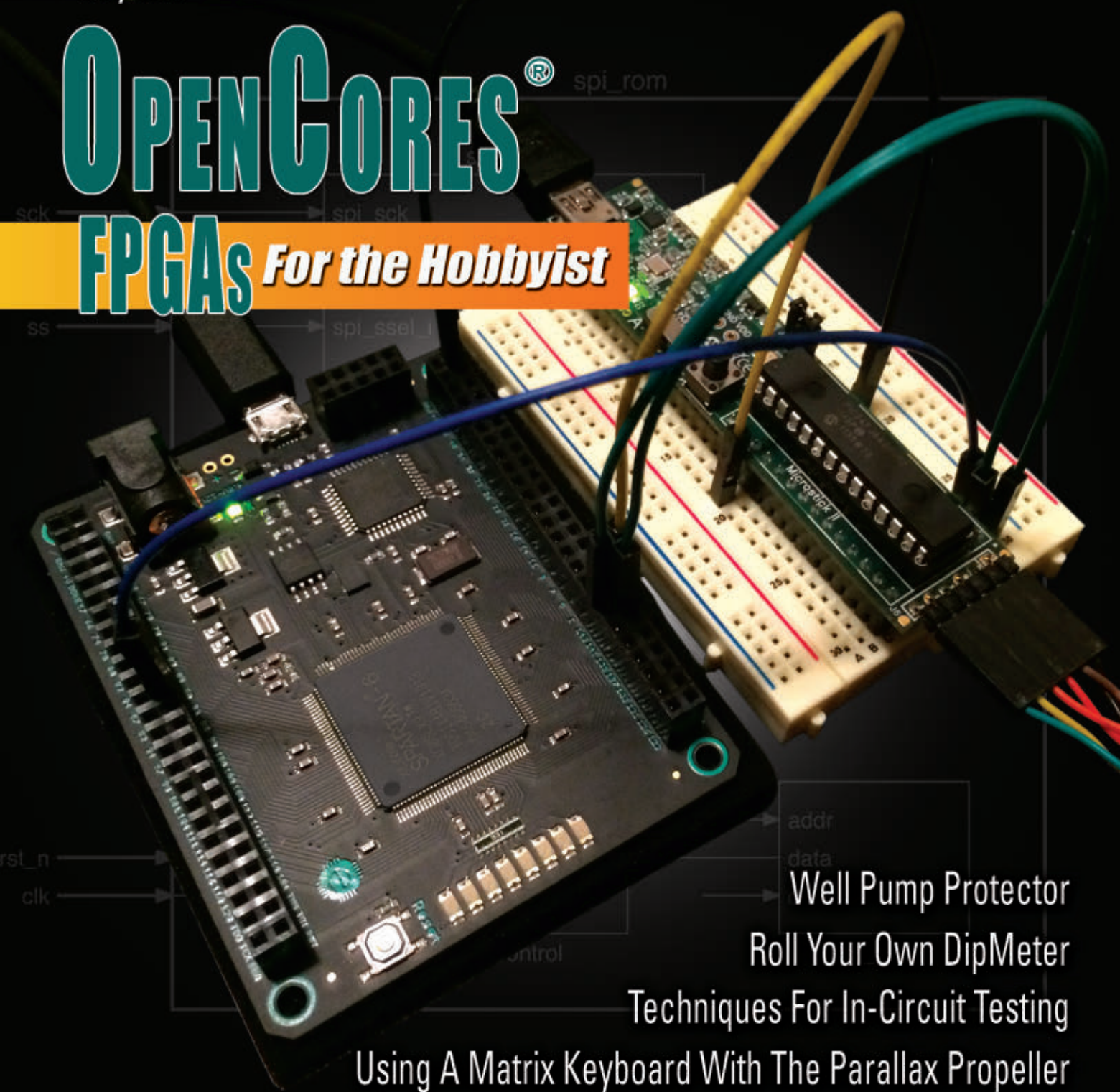
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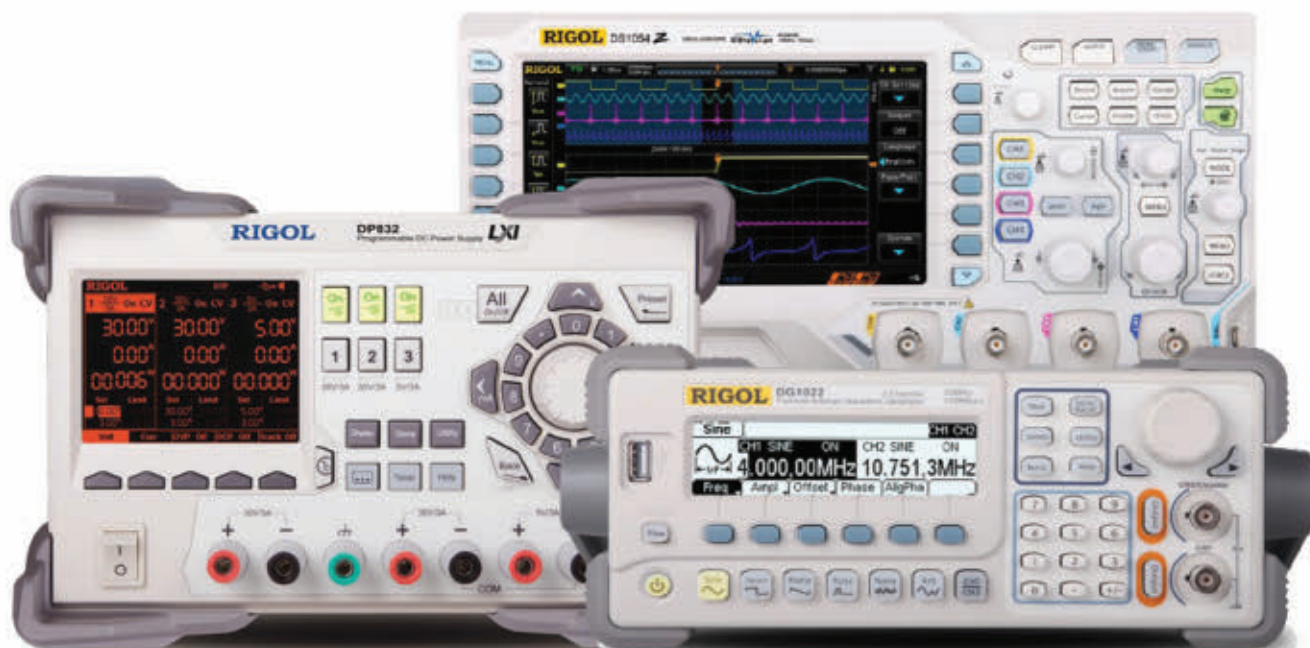
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dai-nuh-moh / dee / seer-eez | noun, plural.

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D945TW	36945	0.16 sec/60°	194 oz-in	0.12 sec/60°	250 oz-in	0.10 sec/60°	319 oz-in	1.57 x 0.79 x 1.50 in	2.40 oz
D950TW	36950	0.23 sec/60°	292 oz-in	0.17 sec/60°	403 oz-in	0.14 sec/60°	486 oz-in	1.57 x 0.79 x 1.50 in	2.40 oz
D980TW	36980	0.28 sec/60°	361 oz-in	0.21 sec/60°	500 oz-in	0.17 sec/60°	611 oz-in	1.72 x 0.88 x 1.57 in	2.76 oz

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24 DIP Meter with Digital Frequency Display

DIP meters are used to determine the frequency of tuned circuits. This device covers a frequency range of 1 MHz to 56 MHz, and can also be used as a frequency counter.

■ By Larry Cicchinelli

34 Water Pump Protection System

You will be "well" served by this five-component (or less!) project that helps protect your water supply.

■ By Joe Bidwell

40 Adjustable Electronic Load Using Incandescent Lamps

Give humble light bulbs a new life as visual indicators in a very handy piece of test equipment: an adjustable electronic (power) load.

■ By Paulo Oliveira

06 TechKnowledgey 2016

Events, Advances, and News

Interesting topics this time include cloaking that's not just for Star Trek anymore; a new smartphone that has a DSLR-level camera; a complete test lab housed in a tiny box; a nightlight for your toilet; plus some other stuff.

10 The Ham's Wireless Workbench

Practical Technology from the Ham World

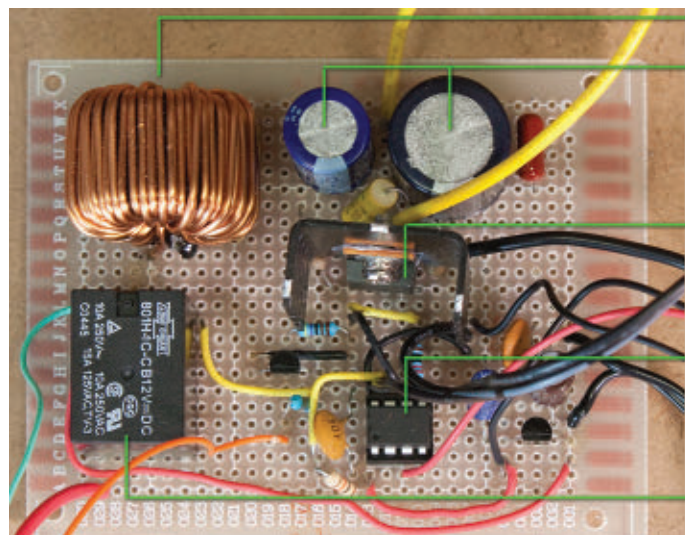
Waves and Propagation: Part 2

Last time, we covered a bunch of basics like definitions of terms and fundamentals of how waves travel. Let's put that knowledge to work with a few interesting opportunities for experimentation.

16 Q&A

Reader Questions Answered Here

Problems with a digital clock's backlight, and "miracle" energy sources and perpetual motion machines are discussed.



Page 40

48 FPGAs for the Hobbyist: OpenCores

OpenCores.org is the leading website related to open source hardware IP-cores for field programmable gate arrays. The challenge of using a third-party IP-core is how to integrate it into your chosen FPGA platform. The goal of this article is to take a fully functional and complete core from OpenCores.org and integrate it onto the Mojo V3 development board.

■ By Ryan Clarke

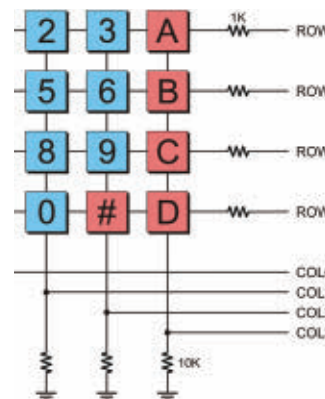
56 In-Circuit Testing Techniques

It is often impossible to directly measure the resistance of resistors because of the presence of parallel current paths. Let's see what we can do about that, and then take a short quiz to test our knowledge.

■ By Richard Agard

59 The Spin Zone Adventures in Propeller Programming

The Key to the Code Matrix keypads are not terribly sexy and exciting. However, they are very useful for stand-alone embedded projects such as puzzles and locks for escape rooms.



Departments

05 DEVELOPING PERSPECTIVES

The Art of Electronics: What Constitutes the Atomic Level?

22 NEW PRODUCTS

23 SHOWCASE
47 CLASSIFIEDS
54 NV WEBSTORE
64 TECH FORUM
66 ELECTRO-NET
66 AD INDEX

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DEVELOPING PERSPECTIVES

by
**Bryan
Bergeron,
Editor**

The Art of Electronics: What Constitutes the Atomic Level?

A recurrent theme in my attempt to teach electronics to others is deciding on what constitutes the atomic level of the art; that is, should I discuss the flow of electrons, the fundamentals of Ohm's Law and discrete components, ICs and other component-level modules, or complete devices at the system level? I have to admit a bias toward low level electron physics, simply because that's how I was first exposed to electronics — the flow of electrons or positrons across barriers and through various crystalline lattices. However, building up from first principles doesn't seem to fit with the needs of today's enthusiasts.

For example, take a typical microcontroller. It would take months of study to fully understand the path of an electron from an input pin, through the hundreds or thousands of gates, to one or more output pins. After all that effort, you'd have no better understanding of how the microcontroller operates. No, in this case, a functional understanding at the device level probably constitutes the atomic level. Sure, there are possible exceptions such as internal pull-up resistors in the I/O but — for the most part — a microcontroller can be considered a black box with signal and power inputs and signal output.

The same can be said for single board computers, from smart phones to handheld games. From a system's perspective, there's quite a bit to understand, from both the hardware and software sides. It can take months to fully understand a smartphone platform at a high level, and Ohm's Law isn't going to help in the process.

So, are component-level electronics dead? I wouldn't go that far, but I'd say it has become a niche specialty or interest in the electronics enthusiasts community — akin to those who specialize in tube amplifiers. After all, someone has to work at the component level to design the power supply and other system components in the drones, phones, and other consumer electronics.

Looking at my own work in electronics over the past few decades, I can clearly see the progression from

component to system level work. I started out with tube and transistor checkers on my workbench, and spent much of my time adjusting the bias on tubes and trying to figure out whether a blown transistor was an NPN or PNP variety with an ohmmeter.

Later, when I worked on commercial communications gear, I simply swapped out boards to identify the faulty circuit. The board went back to the manufacturer for repair. I didn't even have to heat up my soldering iron.

Today, I'm more apt to turn on my 3D printer than my hot air reworking station, simply because that's where the action is. I can spend an afternoon creating a robot platform on my printer or the same amount of time replacing a faulty IC on a circuit board. I feel guilty admitting it, but I now get more satisfaction out of creating something of my own design than in simply reworking a circuit. However, time and money being what they are, it's simply fiscally irresponsible devoting hours and dollars to repairing something that can be replaced with a few clicks of the mouse, with immediate drop shipping from China.

Today, I'd rather spend my time building and flying a drone, focusing on high level topics such as power supply selection, battery charge duration, and maximizing RF signal strength, instead of focusing on what's happening in the controller circuit.

Has your interest in electronics evolved over the years, or has it remained steadfast on a particular topic or level? Either way, I'd like to hear your story, and what you've concluded from your experience. **NV**

As mentioned in the March 2016 Design Cycle column, ImageCraft had a drawing to give away three JumpStart MicroBoxes to randomly selected *Nuts & Volts* readers. The lucky winners are: Russ Ramirez, William Dunn, and Kevin Richard.

Congratulations!

For full details, visit <https://imagecraft.com/company/blog/drawing-for-jumpstart-microboxes>.

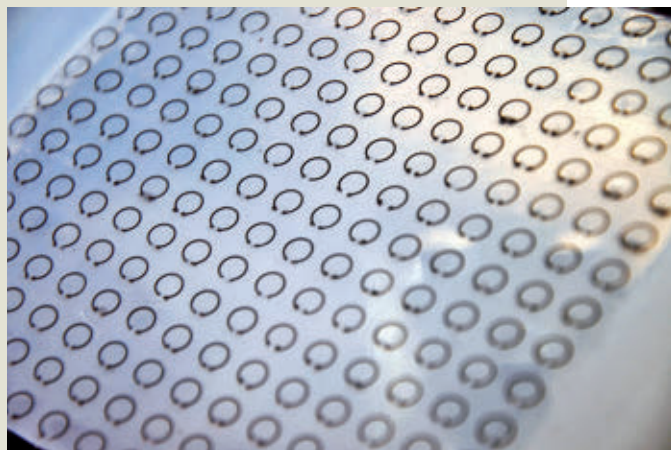
ADVANCED TECHNOLOGY

Cloaking: Not Just for Star Trek Anymore?

Although stealth technology has come a long way, invisibility has remained largely confined to the world of fiction. However, as recently reported in the online journal, Scientific Reports (www.nature.com/srep), some Iowa State University (www.iastate.edu) students appear to have taken a significant step in that direction. Working on the theory that electromagnetic waves — and possibly short wavelengths of visible light — can be suppressed using flexible, tunable liquid-metal materials, they developed a stretchable polymer “meta-skin” that can be tuned to reduce reflections over a wide range of radar frequencies.

The skin consists of rows of split ring resonators embedded in silicone sheets. The electric resonators are filled with Galinstan®: a commercial liquid metal alloy of mostly gallium, indium, and tin. Each resonator is a ring with a radius of 2.5 mm and a thickness of 0.5 mm. The rings have a 1 mm gap, which in effect creates a curved segment of liquid wire. According to the journal report, “The rings create electric inductors, and the gaps create electric capacitors. Together, they create a resonator that can trap and suppress radar waves at a certain frequency. Stretching the meta-skin changes the size of the liquid metal rings inside and changes the frequency the devices suppress.”

Radar suppression was reported to be about 75 percent in the 8 to 10 GHz range. When objects are wrapped in the meta-skin, the radar waves are suppressed in all incident directions and observation angles. Presumably, similar meta-skin could be used to coat future stealth aircraft, but the researchers have their sights set on a higher goal: a cloak of invisibility. According to Asst. Prof. Liang Dong, “The long-term goal is to shrink the size of these devices. Then, hopefully we can do this with higher frequency electromagnetic waves such as visible or infrared light.” ▲



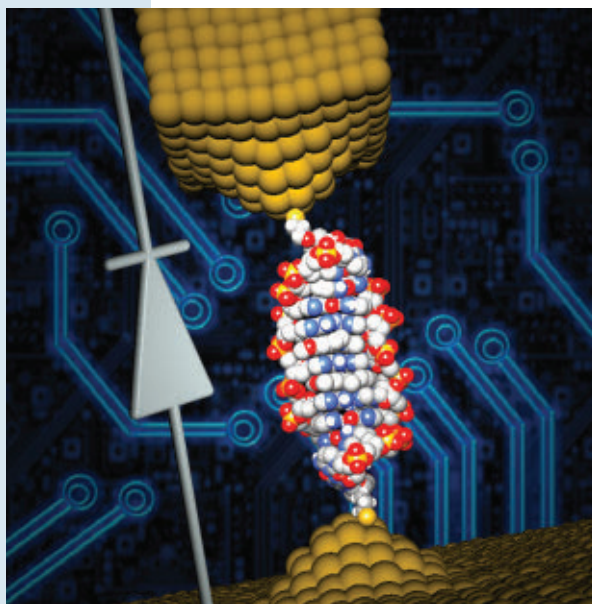
■ This flexible meta-skin can trap radar waves and cloak objects.

Diodes in Your DNA

It's no secret that we've been pushing the physical limits of silicon for years, and silicon-based circuits can't get much smaller without becoming unstable. Looking for alternatives, researchers at the University of Georgia (www.uga.edu) and Israel's Ben-Gurion University of the Negev (in.bgu.ac.il) have discovered that nanoscale electronic components can be made from single DNA molecules. According to UGA College of Engineering Prof. Bingqian Xu, DNA's predictability, diversity, and programmability make it a leading candidate for the design of functional electronic devices using single molecules.

Specifically, Xu and colleagues isolated a specifically designed single duplex DNA of 11 base pairs and connected it to a circuit measuring only a few nanometers. After inserting a small molecule of the chemical coralyne, they found that the current flowing through the DNA was 15 times stronger for negative voltages than for positive, thereby acting as a diode. According to Xu, “Our discovery can lead to progress in the design and construction of nanoscale electronic elements that are at least 1,000 times smaller than current components.”

Research is continuing with the goal of building additional molecular devices and enhancing the performance of the molecular diode which may pave the way to a generation of smaller more powerful advanced electronic devices. ▲



■ Illustration of DNA junction used to create a single molecule diode.

COMPUTERS and NETWORKING

Z Series Workstations Updated

Hewlett Packard (www.hp.com) may be at the top of the laptop heap with its Spectre, Pavilion, and Envy lines, but it remains a major player in the desktop workstation market with its recently “refreshed” Z840, Z640, and Z440 machines. The Z series are “built to address the constraints of compute-intensive industries, including media and entertainment, graphic design, CAD, architecture, photography, manufacturing, finance, healthcare, scientific imaging, and oil and gas exploration” and “offer availability of tested workstation applications from Adobe®, Autodesk, Avid, Dassault, ESRI, SolidWorks, Siemens, and many others.”

All three feature multi-core Intel Xeon E5-2600 v4 series processors, the latest graphics options from NVIDIA® Quadro® and AMD FirePro™, and a choice of Windows or Linux operating systems. The new processors support faster memory speeds (up to 2,400 MHz) and can support up to 44 physical cores per workstation. Each workstation can be expanded with a second-generation HP Z Turbo Drive with 1 TB of PCIe SSD storage, which offers up to four times the read speed of traditional solid-state drives. Thunderbolt 2 connectivity is optional. Base prices were specified at \$1,299, \$1,759, and \$2,399. The Turbo Drive will run you another \$799. ▲



■ HP's top-of-the-line Z840 workstation.

Brave New Web World

You're probably pretty well settled into whatever web browser you've been using and don't feel a lot of enthusiasm for switching to a new one. However, you might consider giving the Brave browser from Brave Software (www.brave.com) a test drive anyway. Notably, it is the brainchild of Brendan Eich, who previously invented the JavaScript language and co-founded Mozilla.

Brave has two basic claims to fame. First, you don't have to install any ad-blocking extensions, as Brave automatically blocks not only advertising, but cookies, tracking pixels, and other gimmicks used to monitor your browsing activity and otherwise invade your privacy. Second, stripping away all of the intrusive junk makes pages load faster.

Brave 0.9.1 was installed, and complex websites such as Weather Underground (www.wunderground.com) were considerably

zipper to load — probably two or three times as fast.

The catch (you know there always is one) is that rather than just deleting the ads, Brave eventually intends to replace them with messages from advertisers of its own.

What you see will be based on your own browsing history, but that info will not be shared with advertisers or even stored by Brave.

Interestingly, Brave intends to give you — the user — a slice of the ad revenues. Payments are to be made in bitcoins and might be enough to buy yourself a pack of gum every month or so. This part of the scheme looks iffy at this point, though, as lawyers for a slew of publishers view this sort of advertising swap as theft and are threatening to sue.

In any event, the free download is currently available for computers running Windows, Linux, or OS X, plus Android and iOS smartphones. ▲

INDUSTRY and the PROFESSION

Cybersecurity Assurance Program Initiated

For as long as any living being can remember, we've been seeing the familiar Underwriters Laboratories (UL) mark on everything from toys to medical devices, and the organization publishes more than 1,400 standards for electronics, smoke and fire equipment, building products, plastics, and other items. In fact, UL is the world's largest not-for-profit testing and certification organization, and its mark appears on some 22 billion products. It's therefore big news that UL has decided to get into the cybersecurity business.

According to several prominent research outfits, there will be somewhere between 21 and 50 billion connected devices by 2020, and by 2018, two-thirds of all networks will experience an IoT security breach. To address the problem, UL has initiated its Cybersecurity Assurance Program (CAP) and has published the UL 2900 series of standards, which "offer testable cybersecurity criteria for network-connectable products and systems to assess software vulnerabilities and weaknesses, minimize exploitation, address known malware, review security controls, and increase security awareness."

UL notes that CAP was developed with input from representatives of the federal government, academia, and industry, and it is recognized by the fed's Cybersecurity National Action Plan. For details, visit www.ul.com/cybersecurity. ▲



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■ The UL mark appears on 22 billion products worldwide.

CIRCUITS and DEVICES

Smartphone has DSLR-Level Camera

Although Taiwan-based ASUSTeK Computer, Inc. — better known simply as ASUS (www.asus.com/US) — ranks as the world's fourth largest PC vendor in terms of unit sales, it hasn't exactly caught fire in the US. However, industry analyst Counterpoint Research has reported that ASUS smartphone shipments increased by 500 percent last year, making it the fastest growing brand anywhere. One of the reasons could be the ZenFone Zoom, recently introduced to North American buyers.

The immediate question one might ask is, "Is it a phone with a built-in camera or a camera that's also a phone?" It is, in fact, an Android smartphone, but it sports a 13 MP PixelMaster rear camera with a 3X Hoya optical zoom lens. The 10-element lens also does close-ups with up to 12X total magnification, and the built-in optical image stabilization system minimizes shaky and blurred shots.

The rear camera also features a dual-LED flash that is balanced to create natural illumination for indoor shots, and the auto-focus feature allows you to point and shoot in just 0.2 seconds. In addition, the ZenFone has a 5 MP wide view front camera. The system is powered by a 64-bit quad-core Intel Atom processor with 4 GB of RAM, and the display is a 5.5 inch 1920 x 1080 HD Gorilla Glass panel. The current street price for an unlocked unit is \$399. ▲



■ The ASUS ZenFone Zoom smartphone.

CIRCUITS and DEVICES Continued

Test Lab in a Tiny Box

Multifunction test instruments are pretty common, but not many are quite as multifunctional as the SF series of USB oscilloscopes from Analog Arts (www.analogarts.com). Each one turns your computer into different devices with capabilities that vary among the four models. At the top of the line is the eight-in-one SF880, which gives you a 100 dB frequency response analyzer, 150 MHz arbitrary waveform generator, 1 GHz oscilloscope, spectrum analyzer, data recorder, frequency and phase meter, 200 MHz logic analyzer, and 100 MHz pattern generator.

At the low end is the six-in-one SF610, which omits the last two devices previously mentioned, but still offers a 70 dB frequency response analyzer, 10 MHz arbitrary waveform generator, 100 MHz oscilloscope, spectrum analyzer, data recorder, frequency, and phase meter.

Each 3 x 5 inch model works with any Windows machine with a USB port, and no external power supply is required. Free demo application software is included, which demonstrates the operation of each

instrument. Prices range from \$640 to \$920. ▲



■ Analog Arts' SF880 provides eight test instruments in one.

Light Up the Night

Maybe you are toilet training the kids. Maybe your overactive bladder medicine isn't working. Or, maybe Uncle Guiseppe — who drinks a lot and has bad aim — is visiting for the week. In any case, you need a GlowBowl toilet nightlight.

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Waves and Propagation: Part 2

*Want to hear the world turning?
You can — it's right behind the front panel of a radio!*

In Part 1 in the May 2016 issue, we covered a batch of basics: definitions of terms, and some fundamentals of how waves travel about. Not only hams can take advantage of radio propagation — everybody has a chance to experience some very interesting ways of interacting with the natural world through wireless. Let's put that know-how to work!

The Radio Horizon

To most people, “using a radio” means the short-range “walkie-talkies” used by public safety agencies and as the Family Radio Service “walkabouts” available to everyone. If pressed, they might also realize that mobile phones, Wi-Fi, and even Bluetooth links are a type of radio, too. The expectation for all those radios is the signals can only be heard within “line-of-sight” range.

A radio wave traveling between two points within line-of-sight range of each other — without bouncing off or bending around anything — is called the *space wave*. How far can a space wave travel between two stations? On a really, really clear day in a wide open area like the Great Plains, you can actually see all the way to where the curvature of the Earth blocks your view of anything more distant. This is the *geometric or optical horizon*. The farther you are above the ground, h , the farther you can see, d , according to the formulas:

$$d(\text{km}) = 3.57 \sqrt{h(\text{in m})}$$

or

$$d(\text{mi}) = 1.22 \sqrt{h(\text{in ft})}$$

Typically, humidity and dust obscure the view and you can't really see that far. At the longer wavelengths of radio, the distribution of impurities in the air cause radio waves to travel very slightly faster at higher altitudes. As the speed of the wave changes, the wave is *refracted* or bent very slightly, just like when light is refracted when it changes from one medium to another. (Think of the

classic demonstration with a pencil in a glass of water appearing to bend at the water's surface.) This refraction — while slight — causes the radio waves to gradually bend back toward the Earth's surface so they can be “seen” at longer distances than light. This is the *radio horizon*.

The distance to the radio horizon also depends on height, as shown in **Figures 1A** and **1B**. **Figure 1A** shows a transmitter (T) and a receiver (R) with antennas located at heights H and H_1 , and radio horizons D and D_1 , respectively.

The chart (**Figure 1B**) shows how to determine D and D_1 . Just find the radio horizon distance for each station and add for the longest possible radio line-of-sight distance. (Note the dashed line in **Figure 1B** showing the slightly shorter distance to the optical horizon at equal heights. In the previous equations, change the constants to 3.86 and 1.32 to calculate the radio horizon.)

Ground Wave

This atmospheric refraction becomes less effective at lower frequencies (longer wavelengths). Below VHF (see the **sidebar** on

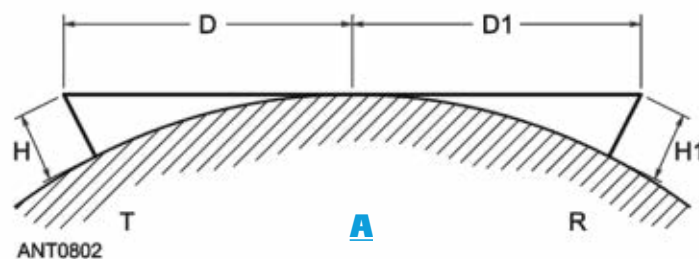
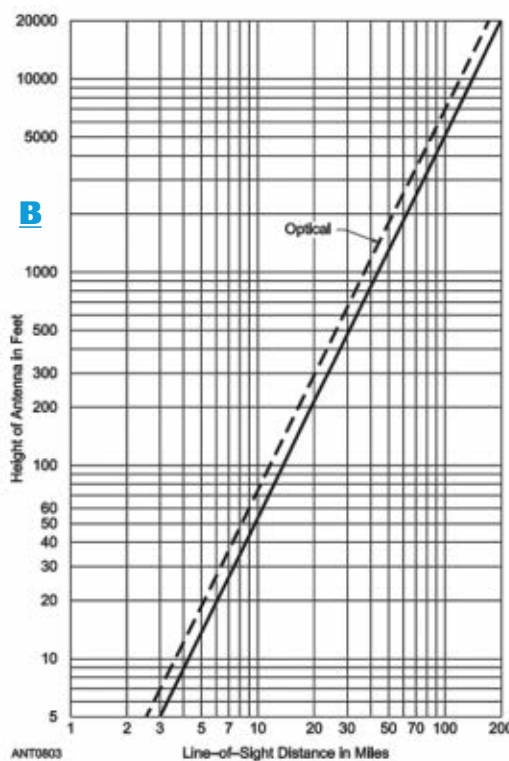


FIGURE 1. Line-of-sight distance between two stations is determined by the height of each station (A). The chart at B shows the distance of both the optical and radio horizons for a single station. Determine the horizon distance for each station and add them for the total line-of-sight distance between the two stations. Graphic courtesy of the American Radio Relay League.

Frequency Range Abbreviations

MF (Medium Frequency)	0.3 to 3 MHz
HF (High Frequency)	3 to 30 MHz
VHF (Very High Frequency)	30 to 300 MHz
UHF (Ultra High Frequency)	300 to 3,000 MHz
SHF (Super High Frequency)	3 to 30 GHz
EHF (Extremely High Frequency)	30 to 300 GHz

Frequency Range Abbreviations) in the HF and MF range, the space wave is still important but another phenomenon becomes significant: *ground-wave propagation*.

Radio waves can travel along any surface or interface between two media in which the wave travels with different velocities. The surface of the Earth is a good example and waves do travel along it. Known by its technical name of “dirt,” the Earth is actually quite lossy at almost all frequencies, converting the electromagnetic energy to heat, or “worm burning” as hams call it. So, as the wave travels along the ground, it is rapidly attenuated.

Ground loss gets higher with frequency, so the ground wave is most effective at and below HF. The typical range of a 10 meter (28 MHz) or CB (27 MHz) ground wave signal is about 5-10 miles depending on the terrain. At AM broadcast frequencies in the MF range (0.5 to 1.8 MHz), the ground wave can be received out to 100 miles or so. That’s why you can listen to the local AM stations even well past the calculated radio horizon.

Tropospheric or Weather-Related Propagation

Remember that statement about changes in wave velocity causing the wave to bend? In the May column, you learned that wave velocity is determined by the permittivity and permeability of whatever medium the wave travels through. Permittivity is what determines a material’s *dielectric constant* — the same dielectric constant used to determine capacitance.

So, wherever dielectric constant changes, the wave’s velocity and thus its direction also change. Does this happen in the atmosphere? You bet!

There are a lot of instances in which the dielectric constant changes — often abruptly — in the lower atmosphere, known as the *troposphere*. These are caused by weather-related events: storms, cold and warm fronts, even temperature inversion layers.

Anywhere there is an abrupt change in the atmosphere, the effect on radio waves is almost as if they were reflected from the air having a different dielectric constant. Propagation of radio waves between two points by using this reflecting effect (even though it’s really a sharp bend created by refraction) is called *tropospheric propagation* or just “tropo” by hams.

Figure 2 shows a typical example of how tropo might

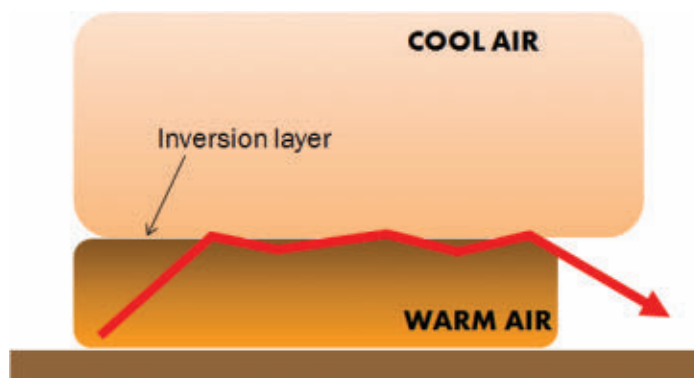


FIGURE 2. The inversion layer between warm air trapped near the ground and colder air above it. The change in dielectric constant between the two regions causes refraction of radio waves and can conduct the waves along the inversion layer for long distances.

occur along the inversion layer that builds up whenever there are stable conditions near the ground. A layer of warm air — often humid and dusty — builds up but is trapped under the cold dry air above.

You can see where the inversion layer is from a plane when taking off or landing — it’s the darker colored air on which the clouds seem to rest. If you can launch a radio signal along this layer at a shallow angle, it can travel for quite a distance! Tropo contacts from this and similar effects can be made at VHF and UHF frequencies — even microwaves — over hundreds of miles.

During microwave contests, hams put up portable stations at high places (such as in **Figure 3**), hoping for the best possible angle for tropo.

Since you can’t “see” tropo, how do you know when it’s happening? A surprisingly easy way is available to everyone by using an ordinary FM broadcast receiver and a simple outdoor antenna, such as a folded dipole or

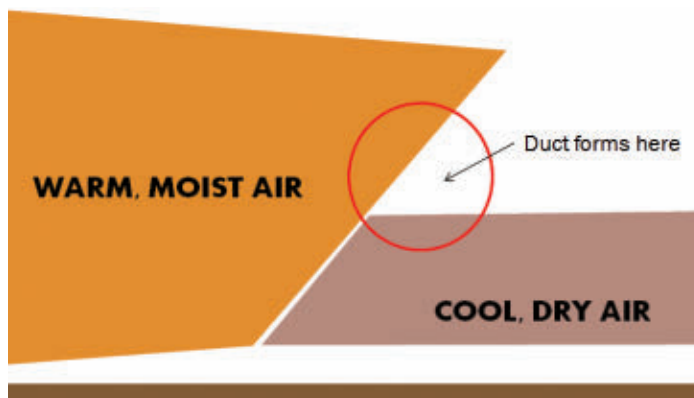


FIGURE 3. A duct can form between two layers of air with different properties or (as shown here) along a weather front. In this case, the warm moist air of a storm system has pushed over the top of a cooler layer, creating two separate refracting “walls.” Signals can be trapped in the duct until one of the layers disperses, allowing signals to reach the ground again.

But Why A Duct?

One variation of tropospheric propagation is referred to as “ducting.” This occurs when more than one reflecting (remember, it’s really refraction) layer is present. A signal can be trapped between the layers and bounce between them until one layer disappears and lets the signal out of the duct.

Figure 3 gives a typical example of how ducts are created by a storm front. Whenever a strong front moves through your area, that’s a good time to have your FM receiver on and listening to that “empty” channel. You may get a big surprise!

Hams know to aim their antennas parallel to the front as it moves through, hoping for a duct to form and carry their signals far from home.

Does Propagation Really Matter?

To most short-range links like Bluetooth and Wi-Fi, line-of-sight and tropo don’t have a significant effect. Once you start considering longer range point-to-point links or receivers on the tops of buildings or hills, you should be aware of the potential for tropo to disrupt communication. Hams may enjoy “working DX” over long distances but if you’re just trying to shovel bits, a signal from far away is not something you want to receive.

Interfering signals or distortion caused by multi-path from ducts or inversion layer propagation can shut down a comm link or cause loss of contact with a mobile or airborne platform.

Be aware of the possibilities and have a “plan B” in mind — either on a different frequency band or by aiming your antenna in a different direction.



FIGURE 4. Using portable dish antennas, these hams are attempting to launch 10 GHz signals along the inversion layer that can be clearly seen at the bottom of clouds over the Mt. Washington, NH region.

Shortwave Propagation

The “real DX” comes from propagation using an entirely different — and much higher — region of the atmosphere. Starting at about 30 miles above the ground, the *ionosphere* can bend radio signals back towards the ground where they are received thousands of miles away. The ionosphere is almost a vacuum; in fact, the International Space Station is actually orbiting in the very top of the ionosphere — so

how can it refract a radio wave?

The key is in the name. “Ion” refers to the effect of solar ultra-violet (UV) radiation on the sparse collection of gas molecules in the upper atmosphere. The UV is ionizing radiation energetic enough to free an electron from an atom, creating two free electrically-charged particles: a negative electron and a positive atom. If

combination TV-FM antenna. Tune your receiver to an unused channel and set the receiver to “Mono” which usually enables audio output even if no signal is present.

If you can aim your antenna, point it at a city or region 300 miles or so away with an FM station on that channel — well past the radio horizon. Then, listen on a day when the atmosphere is quiet and stable.

If tropo occurs, you might hear the station fade in (perhaps surprisingly strong) for a few minutes or longer. You’ve just become a tropo DXer! (“DX” stands for distance.)

Another way to predict when tropo might happen is to use *Hepburn maps*. Created by William Hepburn from weather data, these maps (www.dxinfocentre.com/tropo.html) show when and where atmospheric conditions are right for tropo. You can also keep an eye on the real time ham radio contact maps at www.dxmaps.com/spots/map.php to see if any activity is being reported.

Spring and summer are the best seasons for tropo, although it can occur anytime there is favorable weather.

References

ARRL Antenna Book — An extensive collection of antenna designs with a detailed chapter on propagation from MF through microwaves: www.arrl.org/shop/ARRL-Antenna-Book-23rd-Softcover-Edition.

ARRL RF Propagation — Links to articles and resources dealing with propagation: www.arrl.org/propagation-of-rf-signals. Don’t forget the ARRL Tech Portal: www.arrl.org/tech-portal.

Spaceweather — Daily news and articles about phenomena in space, on the Sun, and here on Earth: www.spaceweather.com.

Spaceweather Prediction Center — Real time information on shortwave propagation conditions, including solar and geomagnetic activity: www.swpc.noaa.gov/communities/radio-communications.

enough atoms are ionized in this way, both the permittivity and permeability of the ionosphere change enough that it can refract a radio wave. If the wave is bent enough to return to Earth, that is *sky-wave* or “skip” propagation.

Ionization is created and disappears each day as the Sun illuminates different parts of the Earth, forming into several distinct layers or regions: D, E, and F as shown in **Figure 5**. (The F layer can further split into the F1 and F2 layers during hours of peak illumination.) The D layer is the lowest at around 30-50 miles, with the E layer just above it; the F layers are found at 60-260 miles.

Each layer has different properties and creates different effects as experienced on the ground. (There are also seasonal effects due to the tilt of the Earth’s axis.)

The lowest layer (D) acts mostly as an absorber of radio energy. It is the D layer that soaks up AM broadcast signals during daylight and limits reception to ground wave range. Immediately after sunset, the free electrons *recombine* with the ionized atoms and the D layer disappears.

AM signals can then be bent back to Earth by higher layers and long distance sky-wave reception becomes possible after sunset.

There is a thriving community of “broadcast DXers”

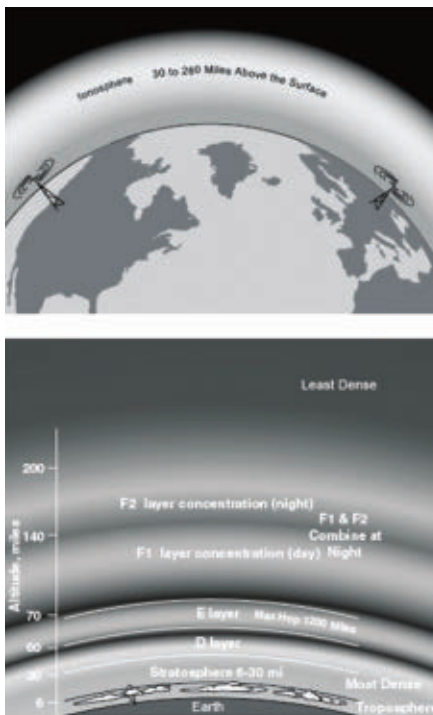


FIGURE 5. The ionosphere forms daily at heights of 30 to 260 miles. Due to variations in density, several different layers are formed, each having a different effect on radio waves. Graphic courtesy of the American Radio Relay League.

who specialize in picking up distant AM stations — sometimes even across oceans.

The E layer — next highest in the stack — is a bit of a mysterious place. Too high to be dense enough for absorbing RF and too low to create reliable long distance communication, its main claim to fame is for reflecting regions called *sporadic E* or *Es clouds*. These patchy regions of ionization are thought to be created by wind shear, compressing metallic ions and dust particles into thin layers.

When ionized by solar UV, these thin layers reflect signals back to Earth, enabling contacts to be made over an average of 1,200 miles. While your FM receiver is on, you may hear stations appear very quickly with good signal levels, last for a while, then fade just as quickly — that’s probably due to *Es*.

Hams operating at 50 MHz enjoy “E skip,” dubbing those frequencies the “Magic Band” for the highly variable — but exciting — propagation far beyond the usual range.

Finally, the F layers are where the real long distance action is for frequencies below 30 MHz — the

traditional *shortwave* bands. In the highly rarified upper reaches of the atmosphere, gas density is very low and the ionized regions may last all day before recombining at night.

Solar Effects

With the ionosphere so dependent on solar UV to exist, it is strongly affected by events on the Sun. The most significant long-term relationship is driven by the 11 year (10.7 years, actually) sunspot cycle in which the number of spots waxes and wanes. More spots equals more solar flux equals better HF propagation equals happy hams and shortwave broadcast listeners!

In the short-term, the Sun is a highly variable source of propagation excitement. Solar flares and coronal mass ejections occur nearly every day at scales from nearly undetectable to massive. Coronal holes and the solar wind send charged particles streaming away from the Sun.

When they encounter the Earth’s geomagnetic field, the fun really begins, creating the auroras and other interesting phenomena that can enhance, disrupt, or even shut down HF propagation entirely.

Numerous websites are dedicated to watching the Sun and its effects here on (or rather, above) the Earth.

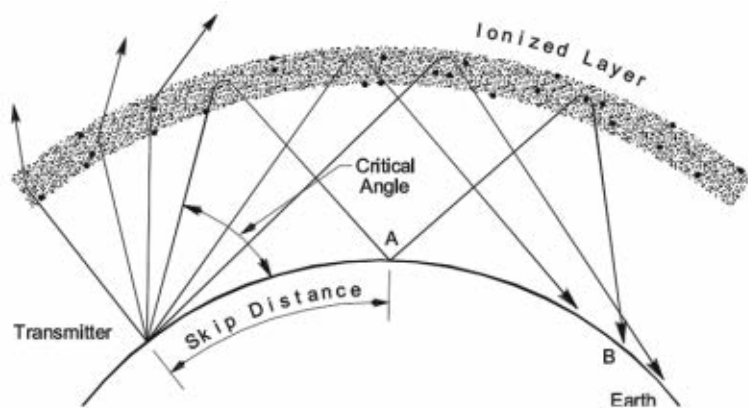


FIGURE 6. The ability of the ionosphere to return signals to Earth depends on the signal frequency and the vertical angle at which the signal encounters the ionosphere. At a sufficiently high vertical angle, the signal cannot be bent enough and is lost to space. The critical angle at a given frequency is the highest vertical angle at which a radio signal of that frequency can be returned to Earth. Graphic courtesy of the American Radio Relay League.

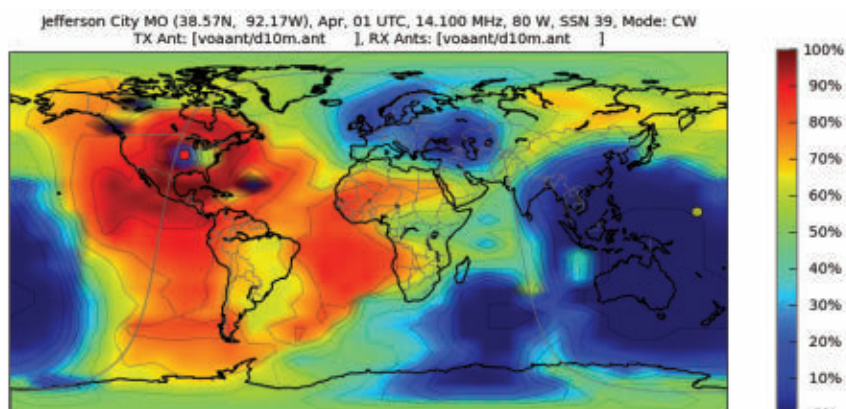


FIGURE 7. VOACAP Online coverage map from Jefferson City, MO at 8 PM in April on the 14 MHz amateur band for stations using half-wave dipole antennas at a height of 10 meters and CW (Morse code). Coverage should be excellent across the Americas, west Africa, and much of the eastern Pacific with current sunspot activity values.

Low density also means it takes a lot of UV to return a signal to Earth — especially at the higher frequencies where less bending occurs. In fact, if the frequency is too high, the signal is eventually lost to outer space as shown in Figure 6.

Assuming the signal is returned to Earth, the distance at which it reaches the ground again is called the *skip distance*, and one such up-and-back trip is called a *hop*. Typical hops involving the F layer span from 1,500 to 2,500 miles on the higher HF ham bands from 14 to 28 MHz.

Note that the signal can also be reflected by ground or water, then make another hop. That's how contacts span the thousands of miles between North America and other continents.

Even though each hop attenuates the signal by about 20 dB (a factor of 100), modern antennas and transceivers are good enough for “solid copy” — even between stations at opposite sides of the planet when conditions are right.

Predicting Propagation

With all this activity and inter-related effects, is it possible to predict ionospheric propagation as Hepburn



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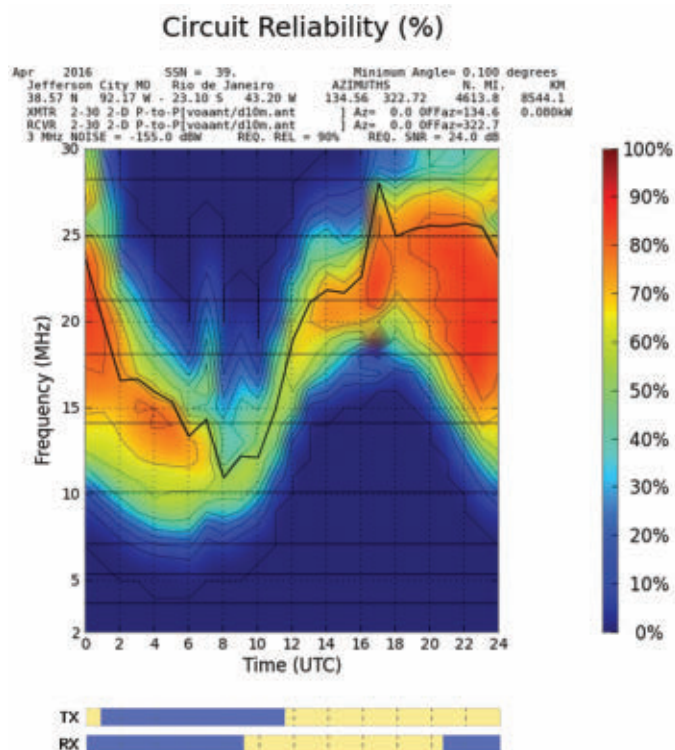


FIGURE 8. VOACAP Online prediction chart for circuit reliability between Jefferson City, MO and Rio de Janeiro with the same stations and solar activity as in Figure 7. The heavy black line represents the MUF — Maximum Usable Frequency — at which communications are possible 90 percent of the time.

maps do for tropo? Yes, and the models are surprisingly accurate! A lot of time and effort was expended studying and modeling HF propagation, resulting in a number of software packages that are used by various communication services, including hams. In fact, one of the best was developed in support of Voice of America broadcasts. It's called *VOACAP Online* and you can experiment with it yourself for free at www.voacap.com.

There are two basic but very useful ways to use the program: coverage mode (**Figure 7**) and prediction mode (**Figure 8**). Coverage mode answers the question, "Given certain station capabilities, where can I expect to make contact on a specific frequency at a given time and date?" Prediction mode answers a more specific question, "On what frequencies and at what times can my station make contact with a specific area on a certain date?"

Give it a try. In coverage mode, select your location from the menu, specify a simple wire dipole antenna at 30 feet for both receiving and transmitting stations, pick one of the shortwave bands, and click "Run the Prediction!" You'll get a colorful map like **Figure 7** showing you where that basic station could make contacts at the time you run the program.

Change the date or time — you'll be surprised at the extent of the changes. You can change from Morse (CW) to one of the voice modes (AM or SSB), change the type and height of the antenna, or see what happens on different bands.

Maybe you have a cousin in Timbuktu. Enter the prediction mode, set up your station, frequency, and time and date to find out when you could have an on-the-air chat. It's really a fascinating program. Not as fascinating as getting a ham license and actually doing it, but fun and educational nevertheless.

References

Of course, we've only scratched the surface of what radio propagation is all about. We started with the basics and now you can see a few of the interesting opportunities for experimentation. The references listed in the sidebar will help you learn a whole lot more.

Maybe we'll even hear you on the air giving propagation a workout! **NV**

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In this column, Tim answers questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions. **Send all questions and comments to: Q&A@nutsvolts.com.**

Digital Clock Backlight Problems

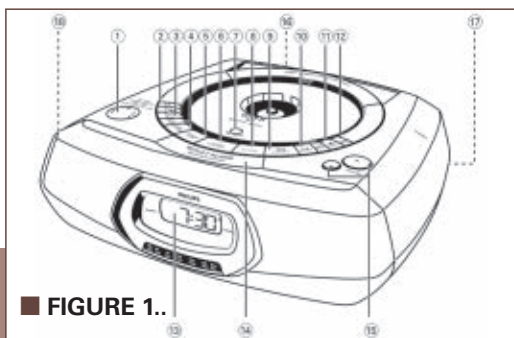
Q I have a Philips Model AJ3936/17 AM/FM radio/disc/alarm clock. It has a yellow backlight that lights up the clock numbers at night with a selector switch that changes from off, to medium intensity, and full brightness. It's gotten where the light just flickers off and on.

Sometimes I can get it to come on by clicking that switch numerous times. It will stay lit for awhile and then go off. Sometimes if you rap it a time or two it will come on like there's a loose component or bad solder joint. It keeps time perfectly though; it's just the lighting feature.

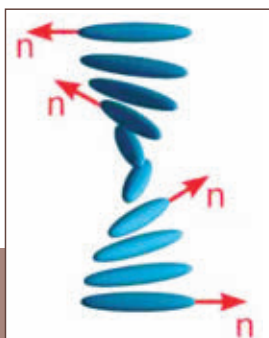
Looks like the module that has the clock numbers and lighting has about 10 or so leads that are soldered into the motherboard. I don't know if it's sort of an argon gas setup or what. Do you have any suggestions other than touching up the solder joints on the motherboard?

Hank Redding
Orange, CA

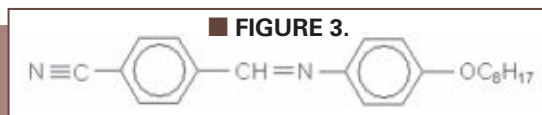
A I have included a link in the Q&A Sidelines for the Philips Model AJ3936/17 Owners' Manual to help with our discussion (schematic not available). (**Figure 1** is the image of the unit as shown in the manual.) I do not see the microswitch you refer to on this model. "Button 14: REPEAT ALARM/BRIGHTNESS CONTROL" is used to adjust the brightness of the display by: (1) Setting the clock control (Button 1) to the CLOCK position; and then (2) pressing Button 14 once or more to change the brightness of the display in the sequence: LOW, MEDIUM, BRIGHT, LOW.



■ FIGURE 1..



■ FIGURE 2. In the twisted nematic liquid crystal director, *n* is the direction in which the long portion of the individual molecules point. Light polarized in the *n* direction passes through the crystal easier. Light is rotated in polarization by the twist of the molecules in the director.



• Digital Clock Backlight Problems

• Perpetual Motion Machines

Unfortunately, manufacturers hardly ever include schematics with electronic devices anymore. There are still some of us in the electronics hobby that love to "tear" into malfunctioning units in hopes of repairing the particular device — even if it costs us more than a new one (*you have to factor in such things as enjoyment and learning which can more than justify the additional costs*).

Before I discuss the backlight problem, let's discuss how a Liquid Crystal Display (LCD) works. I will discuss the twisted nematic liquid crystal theory since these are the types most often used in electronic displays.

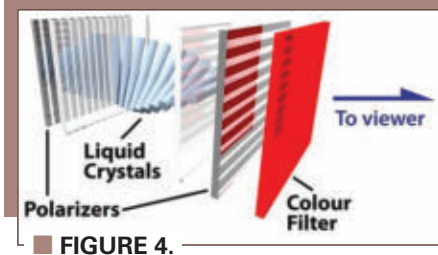
All substances exist as solids, liquids, or gasses. Solids that have their molecules or atoms arranged in an orderly, repeating, and rigid pattern are called crystals (table salt, iron alloys, etc.). Liquids have molecules or atoms which take the shape of the container in which they are placed, and their molecules or atoms can easily move over each other. Liquid crystals occupy the crossover area of properties between a crystalline solid and a liquid.

In a liquid crystal, the molecules are oriented in a very specific direction which gives the crystal optical properties. **Figure 2** shows a series of molecules arranged as a "director" so that the light passing perpendicular to the "n-vector" is rotated in the polarization of its electric field. [*Light — like radio waves — is made up of waves which are a series of electric and magnetic fields perpendicular to each other. The electric polarization of light sources other than lasers is completely random.*]

For those with an interest in chemistry, **Figure 3** shows the molecule 4-cyanobenzylidene-4'-n-octyloxyaniline which can act as a liquid crystal. In this molecule, the atoms are abbreviated as: C for carbon; H for hydrogen; N for nitrogen with the lines between atoms as chemical bonds; and the two hexagons with circles in them represent benzene, each of which has six carbon atoms and four hydrogen atoms, plus the two chemical bonds to the other parts of the molecule. (Whew!) For more information, search for Organic Chemistry on your web browser.

QUESTIONS and ANSWERS

Post comments on this article at
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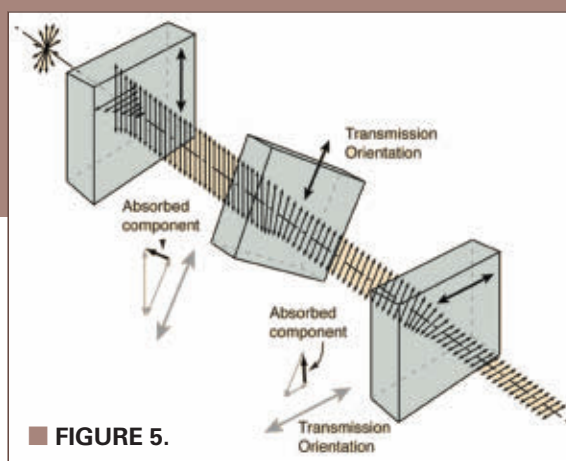
■ FIGURE 4.

Figure 4 shows a single pixel of a liquid crystal display. The twisted nematic director is suspended between two glass plates so that the molecule ends of the director have their long directions (n-vectors) parallel to the adjacent polarizing filter.

Note: A polarizing filter allows light of the polarization parallel to the filter orientation to pass while completely blocking light polarized perpendicular to the orientation of the filter. Light with polarizations between parallel and perpendicular are passed with diminished intensities based on Malus' Law:

$$E = E_0 \cos \Theta$$

where E = the intensity of the light beam after going through the polarizer; E_0 = the initial intensity of the light beam before entering the polarizer; and Θ is the orientation angle between the polarization of the light beam and the polarizer. **Figure 5** shows the polarizer orientations for Malus' Law.



■ FIGURE 5.

polarizer. This light is twisted 90 degrees by the crystal and is transmitted as horizontally polarized light through the polarizer on the right. This makes the area under the electrodes appear clear or the shade of the color filter so the display is blank.

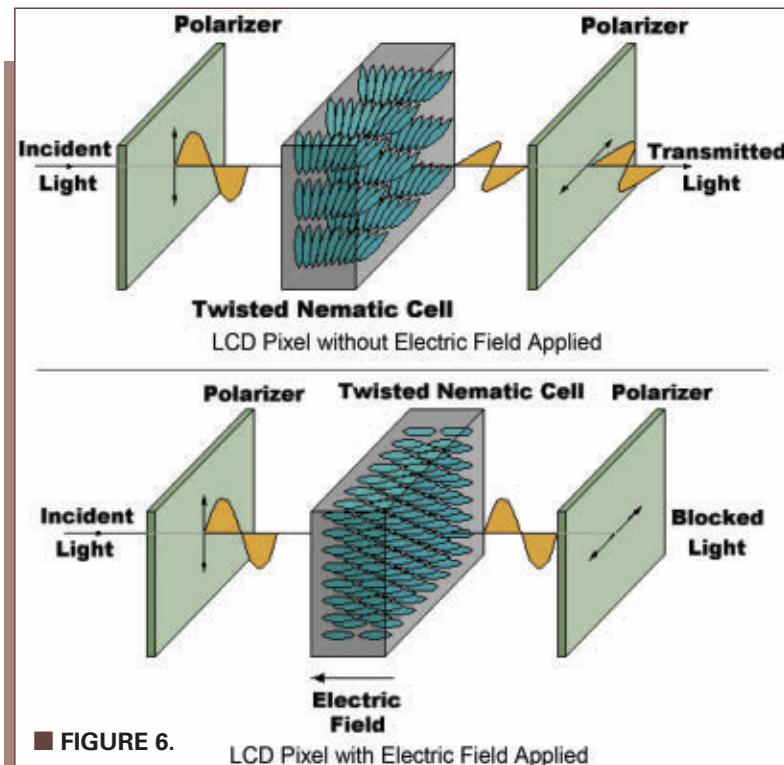
With the electric field applied to the pixel, the twisted nematic crystal untwists so that vertically polarized light enters the crystal from the left of the polarizer. This light is twisted zero degrees by the crystal (remains vertically polarized) and is blocked at the horizontal polarizer on the right. This makes the area under the electrodes appear dark or black, depending on the contrast setting the character outlined by the electrode is displayed. Color LCD displays use Red, Green, and Blue (RGB) color filters and pixels to generate color images.

Figure 7 shows the exploded assembly construction diagram of an LCD pixel and **Figure 8** shows the LCD pixel with the seven-segment electrodes in place. By turning on (applying an electric field to the segment electrode to block light through that segment) some or all of these segments, the LCD can display numbers zero through nine and several letters. The mirror in **Figure 8** is replaced by the backlight in the LCD of your AM/FM radio/CD player/alarm clock.

Does anyone still remember our original question? Now we know the theory behind how the device works, so let's get back to looking at the backlight problem.

Figure 9 shows the schematic of a clock that uses an LCD display with backlight LEDs connected to the power buss via terminals L+ and L-. Your device looks something like this as far as the display is concerned.

Since the rest of the unit seems to be operating correctly, the first thing I would check is the voltage between the LED terminals which should be close to +5 VDC. A lower voltage or intermittent voltage — as it sounds in your case — would indicate a



■ FIGURE 6.

LCD Pixel with Electric Field Applied

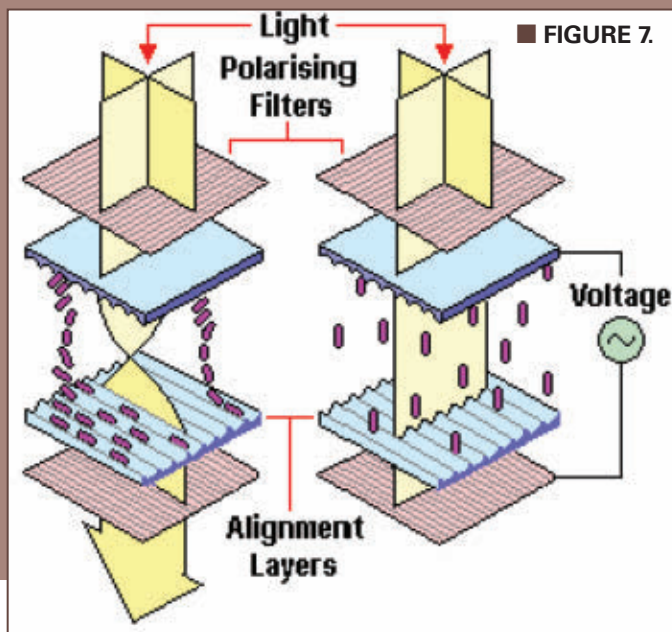


FIGURE 7.

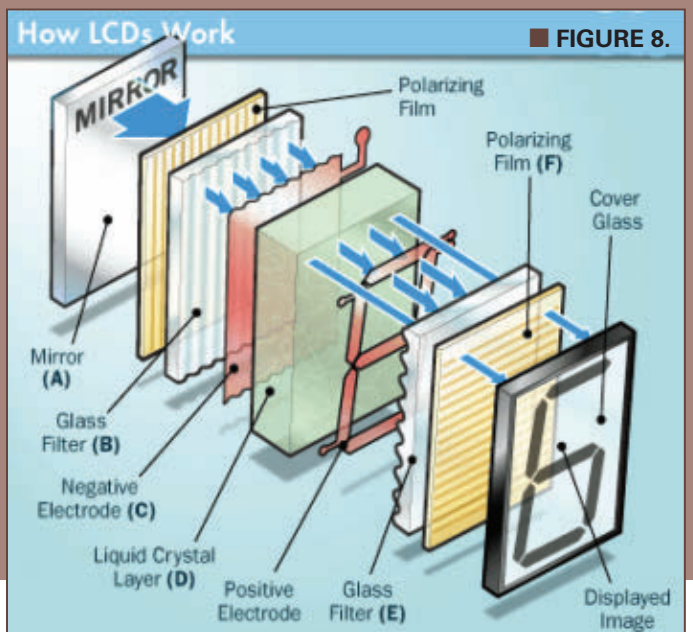


FIGURE 8.

faulty power supply component or a loose connection/bad solder joint somewhere along that power line.

Phillips probably won't provide a schematic, so you'll have to trace the circuit yourself. The biggest problem will be determining the LED power terminals, unless the circuit board is marked or the LCD module datasheet is available. Be aware that many companies do not mark their boards and/or use OEM parts whose data cannot be accessed by the consumer. Troubleshooting tips in most owner's manuals are useless in finding electronic problems.

If the correct voltage is present at the LED power terminals, then the LEDs are bad. This means the entire LCD module must be replaced, which may or may not be available from the manufacturer or an electronics

component supplier. It's a sad state of affairs, but most consumer electronics devices are meant to be "throw away" items which are difficult (if not impossible) to repair by the consumer and too expensive to have repaired by a service center unless the device is still under warranty. (I have had a couple of dive watches that were so expensive it was feasible to send them back for repair).

There may be a chance of installing some LEDs around the periphery of the display module to show the digits, but since this module has a backlight there will be no mirror to help reflect the light back through the digit pixels.

I hope this gives you a starting point for troubleshooting your backlighting problem.

Tim Brown

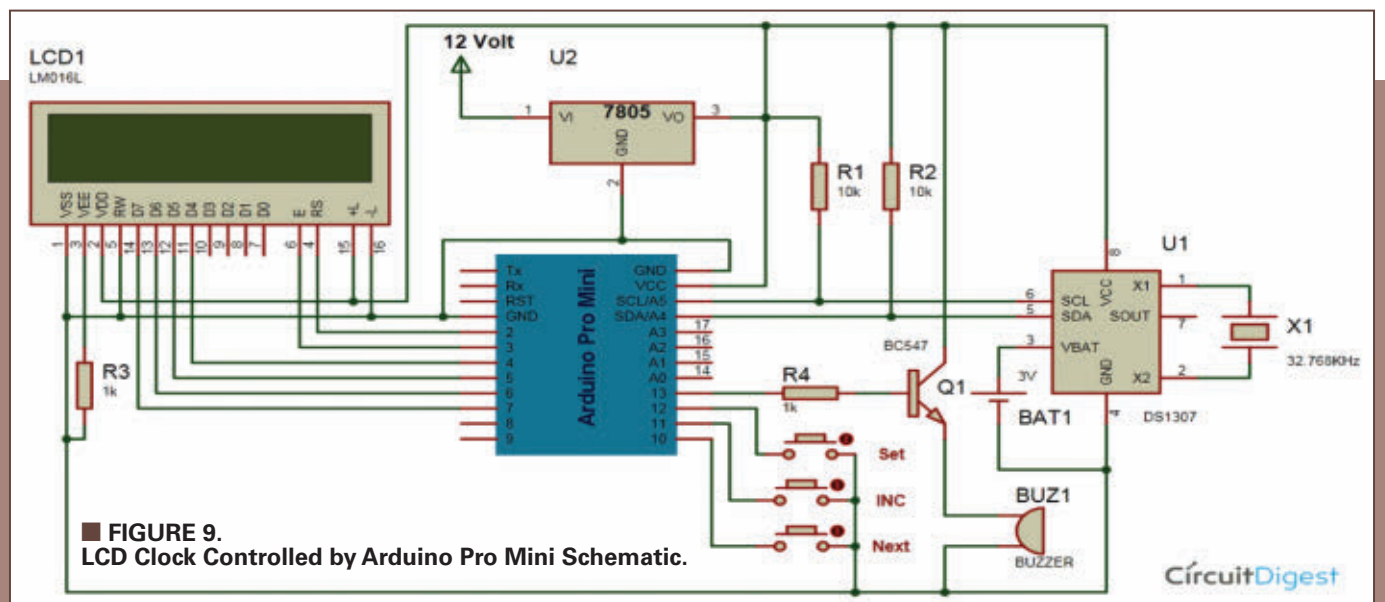


FIGURE 9.
LCD Clock Controlled by Arduino Pro Mini Schematic.

CircuitDigest

Miracle Energy Sources and Perpetual Motion Machines

Q I am seeing a lot of magazine ads and posts on the Internet about devices that can solve our energy problems, but it seems to me that these devices would have to generate more energy than they consume to do what their claims say. What is your take on this?

Cassie Jefferson
Kissimmee, FL

A There is some science to help us see why systems that claim to generate more energy than they consume can NEVER be built EVER! Our search begins in the 1800s with French engineer and physicist, Nicolas Léonard Sadi Carnot who was trying to perfect the steam engine for use in pumping water out of mines. Carnot noted that the power output of the steam engine was proportional to the difference in temperatures between the boiler and the condenser (which represents the heat input into the system). Carnot also noted that part of the heat energy in the system was lost as it left through the condenser water without being made to produce useful work (heat is also lost through the walls of the boiler and piping which cannot be used to generate useful work).

Wait a minute. What exactly is useful work? Hold on to your hats! It's time for a little physics. Energy is defined as the ability to do work, so let's look first at energy.

Energy comes in two major forms: **(1) Potential Energy** – a stationary energy which is the energy of position in a force field such as a raised weight or an electron on a capacitor plate; and **(2) Kinetic Energy** – the energy of motion such as the energy of a weight falling or an electron moving through a conductor. **Figure 10** shows an example of mechanical potential and kinetic energies in a gravitational field using a ball stationary on the top of a hill or pushed down the hill.

With the ball stationary at the top of the hill, the potential energy is maximum and the kinetic energy is zero. As the ball is pushed down the hill, the ball speeds up continually and its kinetic energy increases until it reaches a maximum value at the bottom of the hill. In the meantime, the potential energy decreases until it reaches its minimum at the bottom of the hill. The good thing about potential energy is that we can select the reference plane anywhere in the universe we wish to, but life is easier if we select a plane somewhere in the area we are studying (such as the bottom of the hill in this example).

So, now we can define work in terms of expended energy. Looking at our example of the ball on the hill in **Figure 10**, in order to move the ball from the bottom of the hill as in **(a)**, we had to do work which increased the ball's potential energy (**PE**). When the ball rolled down the hill, it expended potential energy to increase its kinetic energy



FIGURE 10.
Potential Energy = mgh where m = mass of the ball (amount of material in the ball), g is the gravitational constant (9.81 meters/second²) and h = height above a reference plane

Kinetic Energy = $mv^2/2$ where v = velocity of the ball

(**KE**) in **(b)**. Upon reaching the bottom of the hill, the ball is capable of doing work (**W**), such as moving an object in its path.

If there is no energy lost in these two processes, the maximum kinetic and potential energies are equal; they also equal the work done to push the ball up the hill and the work done by the ball at the bottom of the hill. This is the Principle of the *Equivalence of Work and Energy*. The Law of *Conservation of Energy* (energy cannot be created or destroyed but can be transmitted, transferred, or transformed) says in a lossless system (such as our ball on the hill) the net energy is zero or $PE_{in} = KE_{out} = W$ at any point along the path of the ball on the hill.

We cannot have a complete discussion of work and energy without considering the rate at which work is done or energy is expended. We'll call this **POWER**. Power is simple to calculate by dividing the work or energy by the time over which the work was done or the energy was expended:

$$P = W/t = E/t$$

where **P** is the power, **W** is the work done, **E** is the energy expended, and **t** is the time duration over which the work was done or the energy was expended. **Figure 11** is a good illustration of power: climbing stairs.

Let's assume that the "runner" exerts 1,000 Newtons of force (224.8 pounds to lift and accelerate the runner's body weight) to climb the stairs on which the change in height is 10 meters (32 feet - 9.7 inches). The energy required or work done in climbing the stairs is 10,000 Newton-Meters (also known as 10,000 joules). If the "runner" climbs the stairs in 100 seconds, the power is 10,000 joules/100 seconds or 100 joules/second which we know with the familiar power unit as 100 watts (same power as a 100 watt incandescent light bulb consumes).

Let's up the ante and have the runner make the climb in a blistering 10 seconds. Now the power is 10,000 joules/10 seconds or 1,000 watts. In terms of the electric

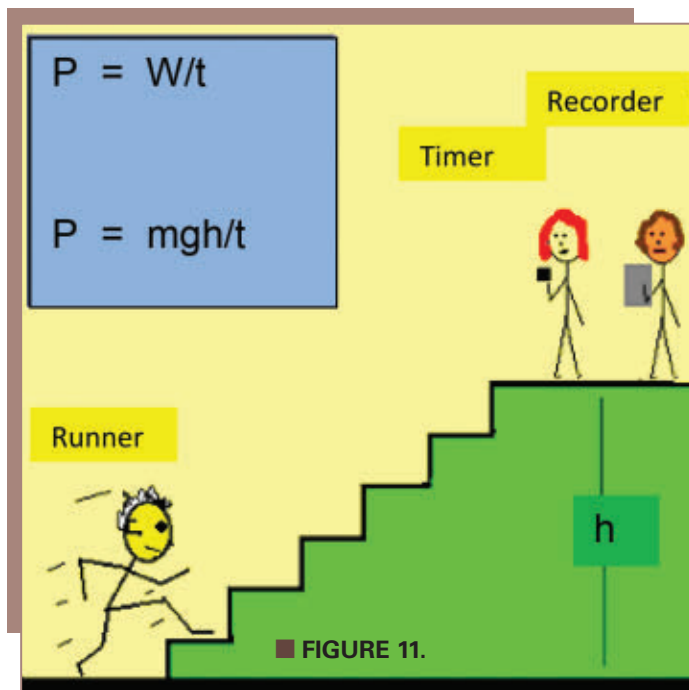


FIGURE 11.

motor power units we are familiar with: 100 watts = 0.13 horsepower and 1,000 watts = 1.34 horsepower. The average healthy human can generate 0.1 horsepower indefinitely and 1.2 horsepower for brief bursts (a lot less with age, injuries, and medical issues); a trained athlete can generate 0.3 horsepower for several hours and 2.5 horsepower for brief periods. So, a human can probably handle the 100 second stair climb easily with little huffing and puffing, but not the 10 second climb which will result in some serious panting.

Now that we have an understanding of energy, work, and power, let's go back to the question of devices that generate more energy/work/power than they consume or — stated in better terms — why they cannot do this. A lot of time, the reality is even that devices consume more energy than the useful work they produce.

Take a look at the power input and power losses in an electric motor as shown in **Figure 12**. We are familiar with the input power which is a product of the voltage applied to the motor and the current passing through the motor from the power line (which can be read with a wattmeter),

and the output power or shaft power used to operate the mechanical load (which is also the power rating listed on the motor's nameplate). We also have to account for mechanical and electrical power losses.

Mechanical losses for the motor only are the bearing frictional losses and windage losses due to the friction between the rotating shaft and the ambient air. Electrical losses are I^2R losses due to current passing through the resistance of the stator and rotor windings, and eddy current losses are due to the currents induced in iron components of the stator and rotor by the varying magnetic field which makes the motor turn.

Manufacturers try to minimize the losses of the motor as much as possible, but the losses are still there regardless of these loss reduction methods. For an induction motor with a 100 watt input power, the output power would be from 85 watts (standard motor design) to 97 watts (energy efficient motor design which costs 25 to 50 percent more than a standard motor). So, for this induction motor, we lose between three and 15 watts of input power.

Efficiency is a convenient way to describe what we are discussing. The efficiency of a device is the output power producing useful work divided by the power input to the device multiplied by 100 percent [Efficiency = $(P_{out}/P_{in}) \times 100\%$]. So, the motor I have given in my example would be between 85 and 95 percent efficient. Efficiencies of various devices we use regularly are: electric motor/generator 85 to 95%; electric transformer 99%; automotive engine 33%; commercially available photovoltaic solar cell 5 to 19%; and microwave oven 50%.

Every device consumes more energy than the useful work it produces. Let's look at a science fair motor-generator system of mine, illustrated in **Figure 13**. The idea sounded simple to my 10 year old mind: start the motor on line current and then switch over so the motor runs the generator which, in turn, produces power to run the motor. My idea would have worked too, if it had not been for those physics laws and their stupid energy losses in the system.

Assuming the efficiencies of 95 percent for both the motor and the generator, with the motor powered by 100 watts from the power line, the motor shaft would produce 95 watts which would be directly coupled to the generator

(no losses). The generator would then produce 90.25 watts of electrical power, so when we throw the switch, the motor now receives 90.25 watts and produces 85.74 watts which it feeds to the generator, which now produces only 81.45

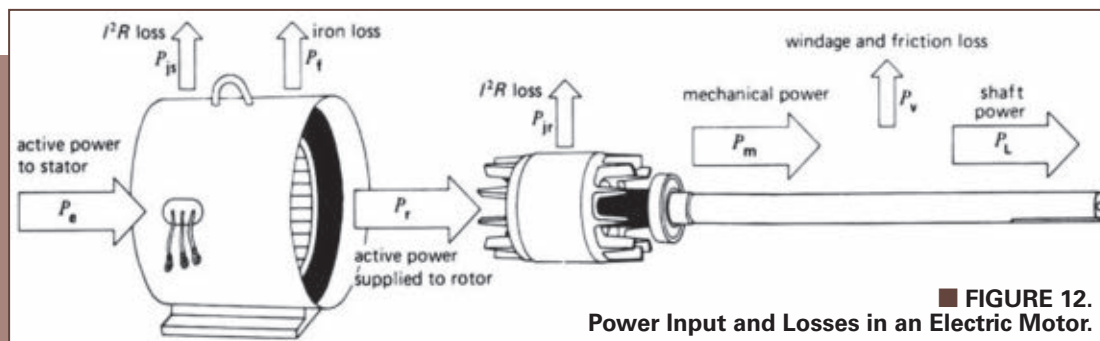
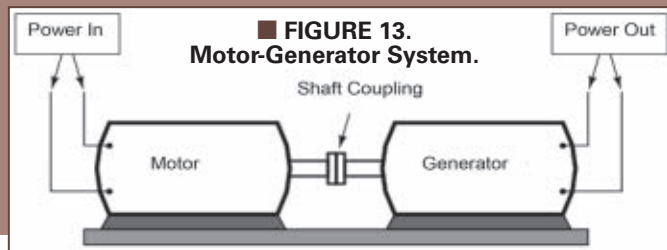


FIGURE 12.

Power Input and Losses in an Electric Motor.



watts to feed to the motor. You can see where this is going ... the motor generator system will run down in short order instead of the perpetual motion I had hoped for.

Figure 14 illustrates a device that appears to produce perpetual motion: the Newton's Cradle. If you take a steel ball from one end of the cradle, pull it back, and release it, the successive transfers of momentum from the balls pushes the final ball out nearly as far as the first ball started. This ball then falls back, starting a new momentum transfer which appears to continue for an infinite amount of time. "Nearly" is the key here because the final ball does not go quite as far as the first ball, but this difference is imperceptible to the human eye (plus, the "infinite amount of time" is actually a lot longer than the average human attention span, so it seems infinite).

Newton's Cradle may operate for a couple of hours, but it eventually runs down and stops due to air friction and the small amount of energy lost each time two steel balls collide. Putting the cradle into a vacuum chamber lengthens the run time, but it still eventually stops going as do all variations of perpetual motion devices.

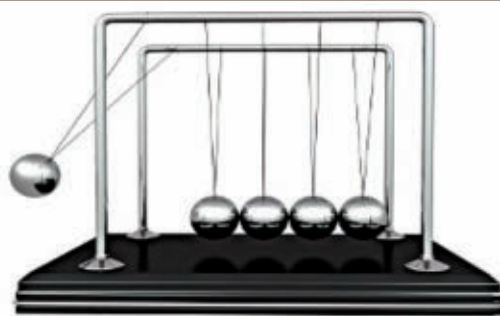


FIGURE 14.
Cradle Illustrates an Illusion of Perpetual Motion.

Besides mechanical and electrical energy, there are also other forms of energy such as: chemical (used in batteries); nuclear; solar; wind; tidal; hydro biomass; fossil fuel; and geothermal. All forms of energy have both potential and kinetic forms (for electricity, voltage is potential energy, and kinetic energy is realized as $P = I^2R$, where P = power dissipated in resistance R due to the flow of current I).

Each of the energies must obey the Law of Conservation of Energy (a.k.a., the First Law of Thermodynamics): "the total energy of an isolated system remains constant — it is said to be conserved over time. Energy can neither be created nor destroyed; rather, it can be transformed from one form to another or transferred." This means that no device can be constructed that will generate more energy that it consumes (i.e., the useful work done by a device is ALWAYS less than the energy used to operate the device).

Nuclear reactors seem to generate more energy than they consume, but nuclear energy generation results in the destruction of some of the mass of the atoms that generate the energy based on Einstein's Equation for the Equivalence of Mass and Energy:

$$E = mc^2$$

where E = the energy generated, m = the mass destroyed, and c = the speed of light in a vacuum (300 million meters per second, or 982 million feet per second, or 186,000 miles per second).

I hope this gives you an insight into the world of energy and how to evaluate scams that claim things that are impossible. For further research, I have listed some Internet resources for potential and kinetic energy in Q&A Sidelines.

Tim Brown

Q&A SIDELINES

Digital Clock Backlight Problems

Philips Model AJ3936/17 Clock Owners' Manual

http://download.p4c.philips.com/files/a/aj3936_17/aj3936_17_dfu_aen.pdf

Miracle Energy Sources and Perpetual Motion Machines

www.softschools.com/difference/kinetic_energy_vs_potential_energy/124/

www.diffen.com/difference/Kinetic_Energy_vs_Potential_Energy

www.wyzant.com/resources/lessons/science/physics/kinetic-and-potential-energy

www.pbslearningmedia.org/resource/hew06.sci.phys.maf.rollercoaster/energy-in-a-roller-coaster-ride/

www.schooltube.com/video/f147084ab011fc64a890/Potential-and-Kinetic-Energy-Wile-E-Coyote-Roadrunner

Figure Credits

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- www.electroschematics.com/5666/liquid-crystal-display/
- www.circuitstoday.com/liquid-crystal-displays-lcd-working
- <http://circuitdigest.com/microcontroller-projects/arduino-alarm-clock>
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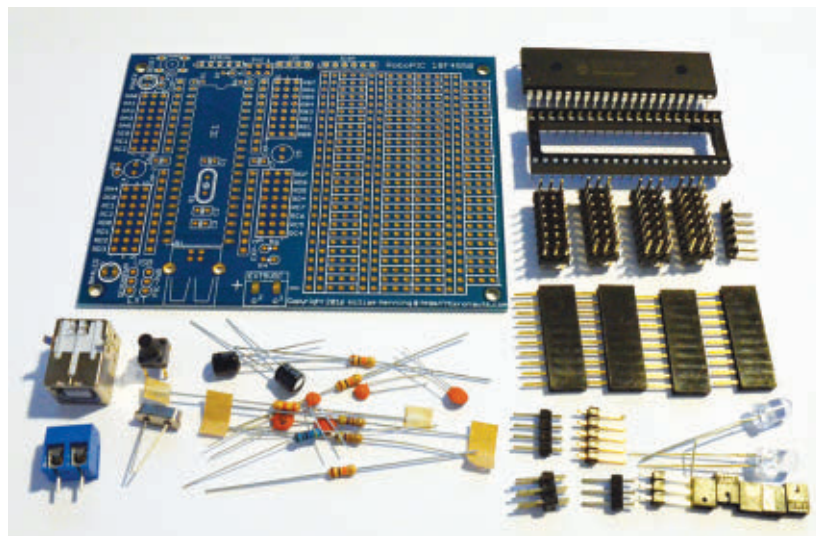
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RoboPIC 18F4550 is supplied in a kit form in order to be more cost-effective for educational institutions and individuals. The full kit is \$34.95 each (+ s/h for qty 1-10). Quantity pricing is available for distributors and educational organizations.

For more information, contact:
Mikronauts
www.mikronauts.com

DUAL-BAND SPECTRUM ANALYZER

Oscium has announced WiPry 5x: a dual-band spectrum analyzer that visualizes 2.4 and 5 GHz on both iOS and Android. By adding coverage to the Android market and supporting 5 GHz, Oscium has expanded their customer base and made some significant improvements. These strategic improvements give Oscium the ability to provide what they believe customers need.

Highlights of the new product include:

- Universal platform (iOS and Android supported)
- 2.4 and 5 GHz dual band spectrum analyzer (RSSI & SSIDs)
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- Portable and easy to use

The host device is now transformed into a perfectly portable troubleshooting tool for all things wireless. WiPry 5x hardware can be purchased for around \$499.

WiPry software is free both in the Apple App Store and on Google Play. Although initial support will only include iOS and Android, the hardware is capable of supporting other platforms such as Windows, Mac, and Linux.

Compatible devices at press time are (listed by operating system):
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- iPhone 6S Plus, iPhone 6S, iPhone 6 Plus, iPhone 6
- iPhone 5C, iPhone 5S, iPhone 5
- iPad Pro
- iPad mini 4, iPad mini 3, iPad mini 2, iPad mini
- iPad Air 2, iPad Air, iPad 4
- iPod touch [5th generation]



Android version 4.0.3 and higher

- All Android devices with USB On-The-Go (USB OTG or just OTG) are compatible.

For more information, contact:
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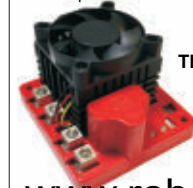
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DIP Meter with DIGITAL FREQUENCY DISPLAY

By Larry Cicchinelli

Post comments on this article and find any associated files and/or downloads at www.nutsvolts.com/magazine/article/July2016_DIP-Meter-Digital-Display.

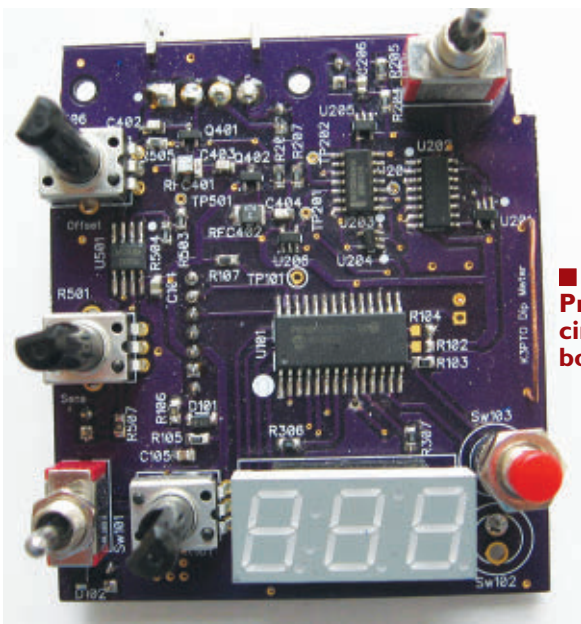
This article describes a DIP meter with a digital display, plus updated components and increased functionality from a version I built back in 1993. This device covers a frequency range of 1 MHz to 56 MHz, and can also be used as a frequency counter. Although the display is only three digits, the counter allows you to view six digits in two groups of three.

The DIP meter discussed here (**Photo 1**) uses a PIC microprocessor for most of its digital requirements instead of discrete logic like my original one. Several of the ICs used in the original unit are very hard to find today.

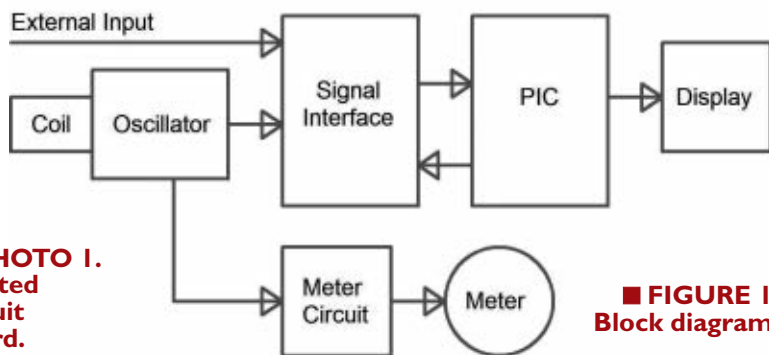
There are two digital functions (not counting some “jelly bean” logic) that are external to the PIC: a divide-by-10 IC and a tri-state buffer. The divide-by-10 IC is used to keep the input frequency to the PIC within its measurement range; the tri-state buffer is used to select between the DIP meter and frequency counter functions, as well as between the direct and the divide-by-10 frequencies. **Figure 1** is a block diagram of the circuit.



There is an excellent article on the usage and operation of DIP meters in the February 2014 issue of *QST*.



■ PHOTO 1.
Printed
circuit
board.



■ FIGURE 1.
Block diagram.

PIC (Schematic 1)

I chose the PIC18F23K22 because its timer 1 circuit has a gate feature that is not available on most other PICs. The signal I use for the gate is derived from the EUSART. The software enables the EUSART in its synchronous mode and creates a series of bytes that enables the gate circuitry. I use the timing and contents of the data bits to create a single pulse which is used as the gate signal for the PIC.

The bit rate is 200 Hz which yields a bit time of five milliseconds. It is then easy to calculate the number of bits required to develop the three gate times I want to use: 10 ms, 100 ms, and one second. The idle state of the data line is high, so I had to program the gate of the timer to be low true. For instance, to generate a 10 ms pulse, all I need to do is transmit a single byte value with two consecutive bits of 0, with the remaining bits as 1s.

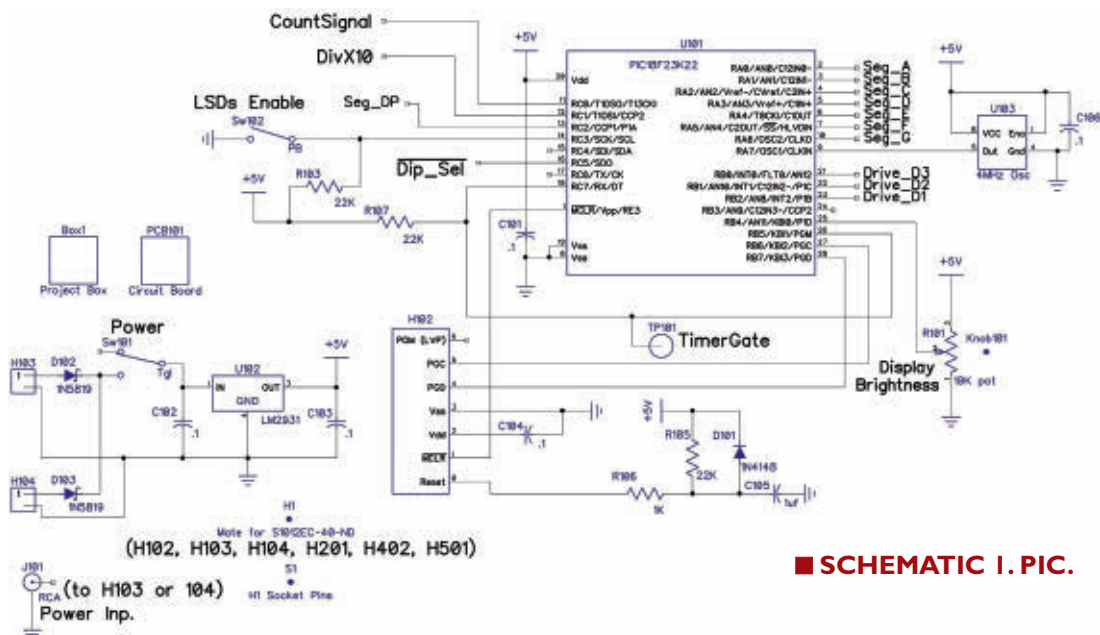
I tried a few methods of generating the gate signal using the EUSART. One of the "features" of the

EUSART is that it starts transmitting bit 0 before the starting edge of the first clock. This means that I cannot use bit 0 of the first data byte. The gate signal is available on TP101.

Note that the programming connector, H102, has a pin 0. This should be connected to pin 1 when the unit is not being programmed in order for the PIC to get the proper reset signal on power-up. I have found that this is not always necessary, but I recommend that you insert the jumper.

The unit draws less than 20 ma at minimum brightness; 35 ma with the brightness control at the midpoint; and about 50 ma at maximum. If you feel that more brightness is needed, you can decrease the value of the current-limiting resistors, R301-R308.

The reason for the two input connectors and diodes is so you can power the unit using a battery mounted inside the case and/or an external power source. The diodes serve two purposes: (1) to protect against reverse polarity; and (2) to allow both power sources to be present simultaneously without damaging either. Using Schottky



What is a DIP meter and what can you do with it?

Basically, a DIP meter is nothing more than a variable frequency oscillator (VFO) with a means of reading its frequency. It can also be considered as a very low power transmitter which puts out a constant unmodulated RF signal (CW). Its main use is to determine the frequency of a tuned circuit.

A Grid DIP meter (Eico) was the second piece of test equipment (after my Heathkit VTVM) I purchased when I got into ham radio. I used it to measure the resonant frequency of the tuned circuits in the transmitters I built to ensure they were set to the correct frequencies. I also used it to measure and then adjust the resonant frequencies of my various antennas throughout the years.

A DIP meter can be used to measure the resonant frequency of a tuned circuit (parallel or serial), a trap, or an antenna. If the antenna is multi-band, you can find each of its resonant frequencies.

If you want to know the values of the L and C in a tuned circuit, you can use formula 2 (in the text) if you have a known capacitor you can put across the circuit. Measure the frequency using the DIP meter both with and without the known capacitor. Plug them into the formula and you will get the L value. You can then calculate the C knowing the L, and the frequency without the known extra capacitor. One of the tables in *FLC Calculations.xls* (available at the article link) makes use of this formula to determine the inductor values required for the different bands of the DIP meter.

You can determine the length of either a shorted or open section of coax by measuring its resonant

frequency. I used this formula to verify the length of a piece of coax:

$$\lambda \text{ inches} = 11811 * VF / \text{FMHz}, VF = \text{Velocity Factor}$$

Attach a short piece of wire to one end of the coax between the center and shield. The wire should be just a couple of inches and formed into a single loop. Now, find the lowest resonant frequency using the DIP meter. If the coax is open at the far end, the coax is 1/4 wavelength. If the coax is shorted at the far end, the coax is 1/2 wavelength.

In my test, the coax was 119" and the measured frequency was 15.7 MHz. Using the formula above:

$$\text{Length} = 11811 * .65 / (4 * 15.7) = 122"$$

which is quite close to the actual length. I then shorted the far end and measured the resonant frequency as 32.7 MHz, which is very close to double the 15.7 MHz measured before. In this case, $\text{Length} = 11811 * .65 / (2 * 32.7) = 117$ — also very close to the actual length.

The variation from the actual length can be due to several factors, such as the VF may not be exactly .65 (my coax is over 20 years old), the adapters I used to get the loop on the end, or the loop itself. I did notice that a longer loop caused the frequency to be lower by 2 MHz with the far end open. This causes quite a difference in the calculated length.

There are many articles on the web you can find by simply entering "what can you do with a DIP meter" into your favorite search engine.

diodes with their lower voltage drop allows for the DIP meter supply voltage to be between 6V and 26V. I selected the 5V regulator because of its very low dropout (LDO) voltage and quiescent current. You can easily use a standard 7805 in the same package if you will not be using battery power.

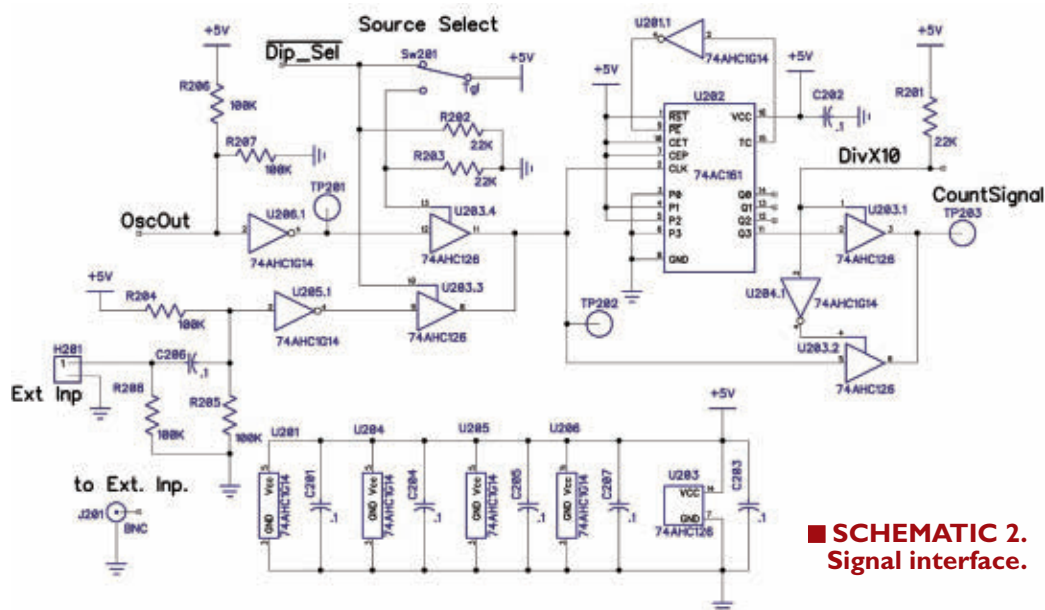
Keep in mind that the circuit will use whichever power source has the higher voltage. So, if you have a

battery installed, be sure that any external power supply you use is higher than the battery voltage. Otherwise, you will still be using the battery.

My first prototype of the DIP meter used RA7 as the signal to drive the decimal point of the display. This seemed to be the obvious choice since the other bits of register A are used for the segments. The measurements for the DIP meter function were quite stable and accurate enough for three digits.

However, when I decided to implement a frequency counter, I found that the accuracy and stability of the internal oscillator were not good enough for six digits. This PIC allows an external CPU clock only on RA7, so I had to find another pin for the decimal point.

Due to some other changes I made, RC2 turned out to be the easiest one to use. The oscillator I selected has an accuracy of 100 ppm, so it is plenty accurate for the DIP meter and okay for most frequency counter applications. There are many oscillators available in this



particular form factor which have better accuracy specifications, but they are more expensive.

The source code for the program is available at the article link. If you do not have a PIC programmer or access to one, I will be happy to program one for you if you send it to me and include an SASE. Email (k3pto@arrl.net) me first to get contact information.

Signal Interface (Schematic 2)

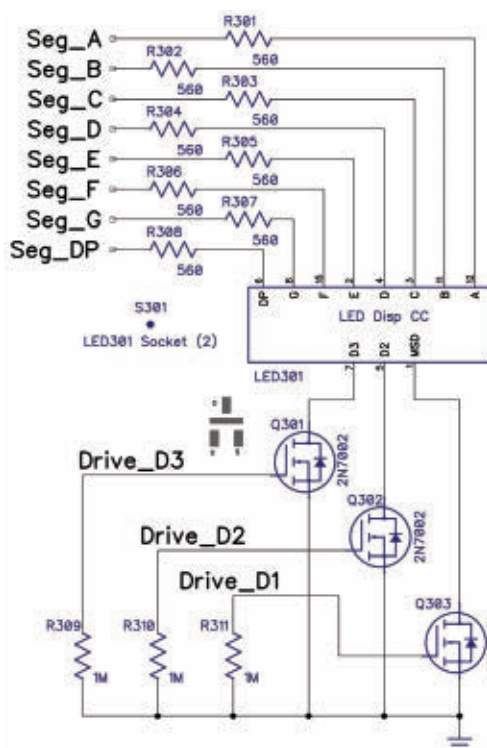
This circuit allows the PIC to select between two signal sources: the output of the DIP meter oscillator and an external input, as well as whether or not to use the divide-by-10 circuit. Both signal sources are buffered by 74AHC1G14 Schmitt triggers. These devices have a limited amount of hysteresis which makes them relatively noise immune. The amplitude of the hysteresis band can be between 0.5V and 1.5V with a 5V supply. The one disadvantage to using this device is that the input signal must be large enough to overcome the hysteresis band. (The oscillator I use has at least 2V peak-to-peak output on all bands.) The resistors on the inputs of these two devices are an attempt to bias the signals to about the mid-point of the window.

As stated previously, the divide-by-10 circuit is needed to ensure that the PIC does not get any frequencies that are too high for its internal counter. The software always takes a preliminary measurement of the frequency using this divider with a 10 ms gate time in order to determine whether or not the divider is necessary. The operation of the 74AC161 is such that when the TC output goes true (count = 15), the inverted TC signal is fed back to the Parallel Enable input, setting the counter to six which yields 10 states – or dividing the input signal by 10. There are three test points available for debugging and/or monitoring signals.

If you intend to use the frequency counter function at frequencies lower than 100 Hz, you might want to increase the value of C206. The reactance of a 0.1 μ F capacitor at 100 Hz is close to 16K. This is on the same order of magnitude as the input resistance of U205.1 due to the parallel combination of R204 and R205 (50K).

Display Circuit (Schematic 3)

There is nothing special about the display circuit except perhaps that I am using FETs to drive the common cathodes. The main reason is that I happen to have quite a few 2N7002s in my parts bins. The gate resistors are probably not needed, but I did not want to have the possibility of floating gates before the program



■ SCHEMATIC 3. Display.

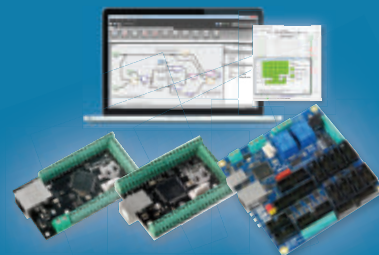
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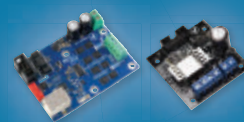
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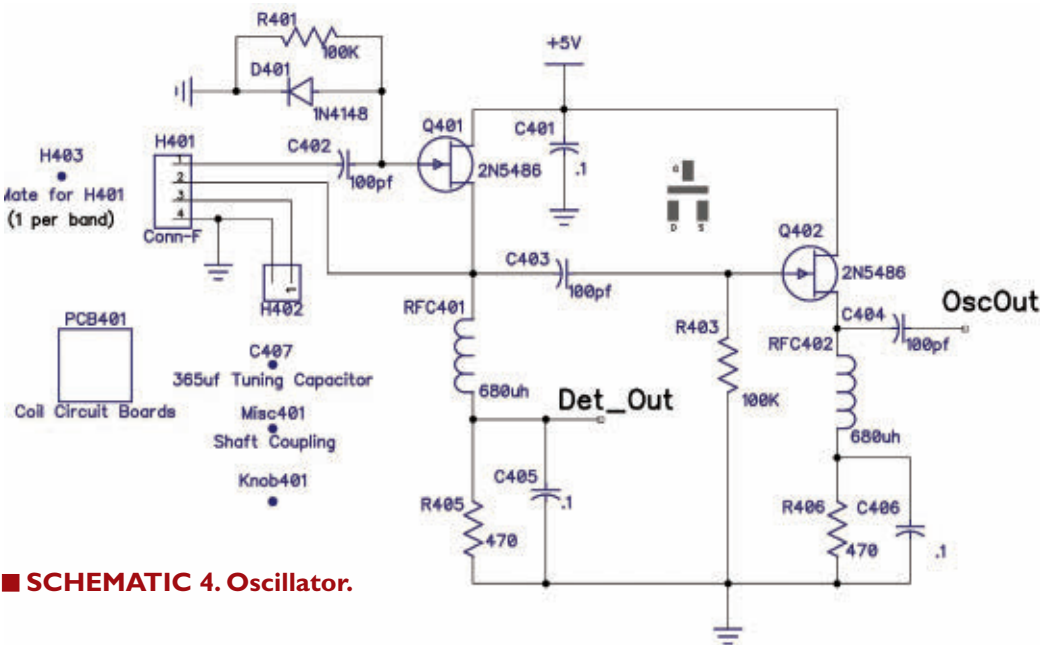
gets through its initialization.

The brightness control is read by the A/D and is used to control the on-time of the segments of the LED display. The program uses only the four most significant bits, yielding 16 brightness levels. With the control fully counter-clockwise, the display is effectively turned off. I selected the values of the current-limiting resistors (R301-R308) experimentally by seeing how bright the display got using a few different values.

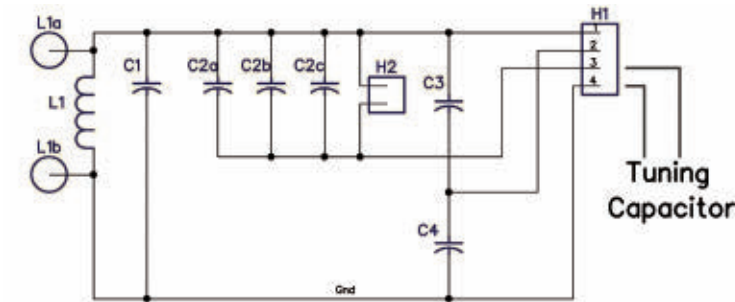
The display is multiplexed in that only one digit is turned on at a time. The on-time is varied by the software within an Interrupt Service Routine (ISR) based on the voltage at the center of R101. I selected the update

frequency by viewing the display and increasing the frequency until there was no flicker. In order to get the display to the same height above the board as the switches, I had to use two stacked 16-pin IC sockets. The sockets have to be cut in half lengthwise since I could not find any sockets the correct width for the display. Not all the pins of the sockets are used — note the position of pin 1 of the display on the PCB (printed circuit board).

Oscillator (Schematic 4) and Coil Circuits (Schematic 5)



■ SCHEMATIC 4. Oscillator.



FLow	FHi	delta_C	L	C1/C2/C3/C4
1.0	2.2	370	54	0/S/100/220
2.0	5.0	370	14.4	0/S/100/100
4.0	10	370	3.6	0/S/100/100
8.0	20	228	1.46	0/660/68/68
18	34	125	0.45	0/220/68/68
32	59	66	.26	0/100/33/33

■ SCHEMATIC 5. Coil.

I believe I spent more time on this circuit than all the others combined. The oscillator is essentially a standard Colpitts configuration except for the location of C402. I decided to implement a source follower using the same transistor as the oscillator in order to ensure that the circuits which follow would not load the oscillator.

For those of you who are interested in circuit synthesis, I have included my files at the article link for LTspice which I used for analyzing the circuit. There are two files which are almost identical: one for the low end of the tuning range

for a particular coil, and one for the high end. I found that it was simpler to have both modeled and viewed simultaneously so I could compare the results. I made the circuit designators in the LTspice models the same as those in the coil schematic.

Photo 2 shows the analysis of the low end of the 8 MHz–20 MHz coil. If you look carefully at the lower left corner of the graphic, on the Status line you will see that it indicates a frequency of 7.95 MHz. I used LTspice to determine values for C3 and C4 that would work well and not have a very long settling time. I did not try to find “optimum” values since I’m not sure I would have recognized them as such.

It was very satisfying to see that the circuit analysis and the formulas discussed next worked out (mostly) in the real world! I say “mostly” because the upper two bands did not work out quite as calculated; they were fairly close, but not as close as the lower bands.

I decided to use a value of 360 pF since they are the easiest to find at a reasonable cost. A search on the Internet yielded several sites that had at least one variable that covered the required range. The company I purchased mine from has two – one of which has an 8:1 reduction drive which would allow finer tuning. I used the standard one (less expensive) for the unit I built.

Notice that column 3 is labeled as ΔC . The formula for frequency can be used to calculate the values in the table given the low and high frequencies by using it twice and solving for two unknowns with two formulas:

Since F_{Hi} and F_{Low} are known, that leaves L , C_{Hi} and C_{Low} as the unknowns. However, we can state that $C_{\text{Low}} = C_{\text{Hi}} + \Delta C$. Also, since I have selected a variable capacitor with known minimum and maximum capacitance values, I can calculate ΔC quite easily. That now leaves us with two


$$L = \frac{10^6}{4 * P^2 * \Delta C} * \left(\frac{1}{F_{Low}^2} - \frac{1}{F_{Hi}^2} \right)$$

The table in **Schematic 5** was developed to make use of this derivation. C_{Hi} is the capacitance required for the high frequency end of the tuning range, and comprises the minimum capacitance of the tuning capacitor, C1, C3, and C4 of the tank circuit plus any strays. As it turned out, I didn't need to use C1 for any of the bands, but I left it there in case it is needed to customize the circuit for a



specific range of frequencies.

C2 is used to reduce the maximum capacitance of the tuning capacitor when a smaller maximum value is desired; the minimum capacitance is only slightly affected relative to the maximum. This is desirable at the higher frequency bands in order to allow a higher inductance value.

Using the spreadsheet, *FLC Calculations.xls* (available at the article link), you can see that if the full 360 pF range of the capacitor is used on the highest band, the required inductance is about 1/6th of the value listed in the table. I chose to reduce the effective ΔC of the tuning capacitor in order to use larger values of inductance, which are easier to implement.

The spreadsheet has several sections that I developed to help me with the tuned circuits of the oscillator. The sheet is password protected (k3pto) to ensure that I don't make any unintended changes to the formulas. The protected cells are highlighted with a yellow background.

The first section calculates frequency, inductance, or capacitance, knowing any two of the three. The next section calculates frequency, inductance/capacitance, and reactance, also knowing any two of the three. Next is the formula to calculate inductance based on coil diameter, number of turns, etc. This is followed by a listing of the turns per inch for several wire gauges.

The next section derives the table shown in **Schematic 5** using formula (2) for inductance as shown above. The last table is the coil winding information for each of the bands.

I wanted to wind the coils on forms that would be relatively easy to duplicate. Five of them are wound on the cases I saved from some pills; they are 0.7" diameter.

Note that one of these five indicates 0.8". That is



■ **PHOTO 3. Coils.**

because I used heavier gauge wire which did not stay tight against the form.

The first coil in the table was wound on an empty thread spool which my wife graciously gave me. I tried several variations of coils on a few bands. They all worked equally well, so if you don't have the forms I used, anything relatively close will work. Simply plug in the diameter of the forms you are going to use and the spreadsheet will calculate the number of turns.

The last line of the spreadsheet shows the inductance for a "stretched" coil. That is, one that is not tightly wound. This is helpful for making a coil with a very low inductance.

The #14 wire I used for the two highest frequency bands was retrieved from a short length of Romex I had left over from some house wiring. The #24 wire is from a spool I've had for over 20 years. I would be happy to mail the required length of #24 wire (as long as it lasts) to anyone who wants to build this project and sends me an SASE. Again, please email me first to ensure I have some left and to get contact info. **Photo 3** shows the six coil assemblies I made for this project.

You should note that with any capacitor tuned circuit, using a standard variable less than the first 25% of the band is covered by 50% of the capacitor rotation. Page 2 of the spreadsheet contains a graph which shows this. The reason I mention this is that you may want to customize one or more bands for the frequencies that most interest you.

The one that first comes to mind is the band which covers six meters. It might be worthwhile to design the oscillator to cover from 49 MHz to at least 65 MHz in order to get good band spread on six meters.

You may wonder why I used #14 wire for the higher two bands. Basically, for two reasons: (1) Fewer turns per inch requires more turns for a given inductance, making it easier to get the desired value; and (2) Making a "stretched" coil is much easier with heavier gauge wire.

I mounted the tuning capacitor to the back wall of the box — the same wall that has the coil socket. I threaded two of the holes in the capacitor body using a 6-32 tap for mounting and 6-32x1/4" bolts. You need to make sure that the bolts do not touch the rotor plate as it is rotated.

If it does, you will need to shorten the bolts. I extended the capacitor shaft using a piece of 1/4-20 all-thread with a homemade shaft coupler to hold them together. You might want to use the shaft coupler mentioned in the **Parts List**.

Meter Circuit (Schematic 6)

The oscillator Det_Out signal is a DC voltage which increases when the coil of the oscillator is brought into

REF/DES	VALUE	NAME	NOTES	VENDOR	QTY	COST	TOTAL
Box1	Project Box	HM323-ND		Digi-Key (DK)	1	\$14.11	\$14.11
C101, C102, C103, C104, C106, C201, C202, C203, C204, C205, C206, C207, C401, C405, C406	0.1	587-1133-1-ND		DK	15	\$0.29	\$4.31
C105	1 μ F	1276-1246-1-ND		DK	1	\$0.10	\$0.10
C402, C403, C404	100 pF	712-1394-1-ND		DK	3	\$0.45	\$1.35
C407	365 μ F Tuning Capacitor	365 μ F Air Variable Capacitor	1		1	\$16.90	\$16.90
D101, D401	1N4148	1N4148WTPMSCT-ND		DK	2	\$0.11	\$0.22
D102, D103	1N5819	1N5819HW-FDICT-ND		DK	2	\$0.44	\$0.88
H1	Mate for S1012EC-40-ND	WM5343-ND	3	DK	1	\$1.05	\$1.05
H102, H103, H104, H201, H402, H501		S1012EC-20-ND	4	DK	1	\$0.36	\$0.36
H401	Conn-F	WM13511-ND		DK	1	\$0.75	\$0.75
H403	Mate for H401	A1972-ND		DK	6	\$0.21	\$1.26
J101	RCA	159485		Jameco	1	\$0.95	\$0.95
J201	BNC	A97548-ND		DK	1	\$1.74	\$1.74
Knob101, Knob501, Knob502		265077		Jameco	3	\$0.99	\$2.97
Knob401		264955		Jameco	1	\$1.09	\$1.09
LED301	LED Disp CC	160-1545-5-ND		DK	1	\$2.91	\$2.91
M501	Meter	315301		Jameco	1	\$9.95	\$9.95
Misc401	Shaft Coupling	36-1453-ND	7	DK	1	\$3.32	\$3.32
PCB101	Circuit Board		2		1	\$13.50	\$13.50
PCB401	Coil Circuit Boards		2		6	\$1.70	\$10.20
Q301, Q302, Q303	2N7002	2N7002LT1GOSCT-ND		DK	3	\$0.15	\$0.45
Q401, Q402	2N5486	MMBF5486CT-ND		DK	2	\$0.42	\$0.84
R101, R501, R506	10K pot	P3C3103-ND		DK	3	\$0.90	\$2.70
R103, R105, R107, R201, R202, R203	22K	311-22.0KCRCT-ND	8	DK	10	\$0.02	\$0.21
R106, R502, R508	1K	311-1.00KCRCT-ND	8	DK	10	\$0.02	\$0.21
R204, R205, R206, R207, R208, R401, R403	100K	311-100KCRCT-ND	8	DK	10	\$0.02	\$0.21
R301, R302, R303, R304, R305, R306, R307, R308	560 Ω	311-560CRCT-ND	8	DK	10	\$0.02	\$0.21
R309, R310, R311	1M	311-1.00MCRCT-ND	8	DK	10	\$0.02	\$0.21
R405, R406	470 Ω	311-470CRCT-ND	8	DK	10	\$0.02	\$0.21
R503, R504	10K	311-10.0KCRCT-ND	8	DK	10	\$0.02	\$0.21
R505	88.7K	311-88.7KCRCT-ND	8	DK	10	\$0.02	\$0.21
R507	Rx	(311-105KCRCT-ND)	6	DK	1	\$0.10	\$0.10
RFC401, RFC402	680 μ H	495-2654-1-ND		DK	2	\$0.67	\$1.34
S1	H1 Socket Pins	WM2562CT-ND	5	DK	20	\$0.11	\$2.28
S301	LED301 Socket (2)	ED3016-ND		DK	2	\$0.75	\$1.50
Sw101, Sw201	Tgl	2135486		Jameco	2	\$1.25	\$2.50
Sw102	PB	26623		Jameco	1	\$0.85	\$0.85
U101	PIC18F23K22	PIC18F23K22-I/SO-ND		DK	1	\$2.27	\$2.27
U102	LM2931	497-1564-1-ND		DK	1	\$0.87	\$0.87
U103	4 MHz Osc	SER2205CT-ND		DK	1	\$2.26	\$2.26
U201, U204, U205, U206	74AHC1G14	296-1092-1-ND		DK	4	\$0.49	\$1.96
U202	74AC161	MC74AC161DGOS-ND		DK	1	\$0.54	\$0.54
U203	74AHC126	296-4534-1-ND		DK	1	\$0.49	\$0.49
U501	TS912	497-6618-1-ND		DK	1	\$1.07	\$1.07

Total cost = \$111.62
Prices may vary.

Notes

1. www.midnightscience.com/catalog5.html#part2
2. www.qsl.net/k3pto
3. Part is cut to size to mate to H102, H103, H104, H201, H402, and H501.
4. Part is cut to size for H102, H103, H104, H201, H402, and H501.
5. Inserts for mate to H102, H103, H104, H201, H402, and H501.
6. Must match your meter — see text.
7. Can make one with two knobs back-to-back.
8. Buying 10 is cheaper than buying three!

PARTS LIST

close proximity to a tuned circuit of the same frequency. However, the operation of the circuit is such that the meter shows a decrease in voltage.

I did this deliberately since most amateurs are used to seeing and hearing about grid DIP meters, so I wanted to keep the usage the same.

The first stage allows the user to adjust for the DC operating point of the drain of Q401 using the offset control. The second stage allows the operator to adjust the gain of the circuit. My suggestion is that you begin operation with both controls set to maximum and then turn down the offset until the meter is at about 3/4 scale. I have found that I always keep the gain at maximum so it is entirely possible to replace the pot with a fixed resistance of 10K.

Notice that I have not specified the value of R507. This is because I do not know what meter may be used. The meter in my unit (found in my parts supply and is probably at least 30 years old) is 4 ma full scale, so I used a 1.3K resistor. Since the maximum current is $5V/R507$, this ensures that the meter will not be damaged no matter what the adjustment settings. The meter listed in the Parts List is 50 μA , so a value of 105K would be appropriate.

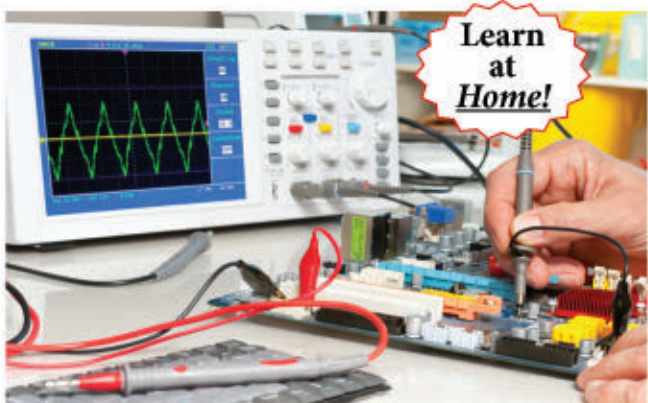
The development of the oscillator circuit and programming the PIC were both very much learning experiences. Using LTspice to analyze the oscillator was a first for me and was quite educational. I would encourage anyone interested in building this project to get the LTspice files and try it yourself. Learning circuit simulation via computer program is a skill which you will probably find very helpful if you want to do any linear circuit design.

Although assembly language is not nearly as popular as C or C++ for programming, I find it a good language for smaller microprocessors. For one thing, it gets you very close to the hardware. I have always liked assembly since I started programming almost 45 years ago when it was a necessity. The source code for the project is available at the article link and is, I believe, quite well documented. **NV**

Construction Notes

These notes are not in any particular order ...

- Circuit Board ordering information will be available on my website; email me for details.
- Coil Boards: When C2 is not used (shown as S in the table), H2 must be shorted.
- Enclosure: I used epoxy to fasten 4-40 nuts to the inside of the bottom piece of the enclosure so that I can use bolts instead of screws to fasten the two pieces together. This allows easier access if a battery is installed.
- Enclosure: The connectors for the External Input and Power do not have to be the ones I used.
- If you use the same method I did for the tuning capacitor, you can use a 1/4" dowel to extend the shaft.
- Main Board: The final PCB is slightly different from the one shown in the photos here and has some minor modifications that make assembly easier.
- Main Board: Most headers and their sockets (H103, H104, H201, H402, H501) do not need to be used — you can simply solder the appropriate wires into the holes for them. I like to use the headers since they make assembly and disassembly much easier.
- Main Board: You may need to trim the sides of the board near the top in order to not interfere with the screws/bolts that tie the two halves of the enclosure together. There are rectangles in the silk screen showing the cuts that should be made.
- Main Board: R101 has its two mounting tabs cut off.
- Main Board: Use two stacked sockets for the display in order to get it high enough to match the height of the switches.
- Main Board: Note that all the SMD resistors are 1%. This is because the 1% values are only 3¢ more per quantity of 10: 18¢ vs 21¢.
- Main Board: Also, for the resistors, the **Parts List** shows quantities of 10 for all the SMD resistors. This is because ordering two is only 1¢ less than ordering 10.



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Water Pump PROTECTION SYSTEM

By Joe Bidwell

Post comments on this article and find any associated files and/or downloads at www.nutsvolts.com/magazine/article/July2016_Water-Pump-Protection-System.



If I turn on a faucet in my home and there's just a sputter instead of water, my heart sinks (no pun intended). If I were on a municipal water system, I would just wait until service was restored. However, my family's water comes from a deep well on our rural property in Arizona; so when the water stops, it's my problem to solve.

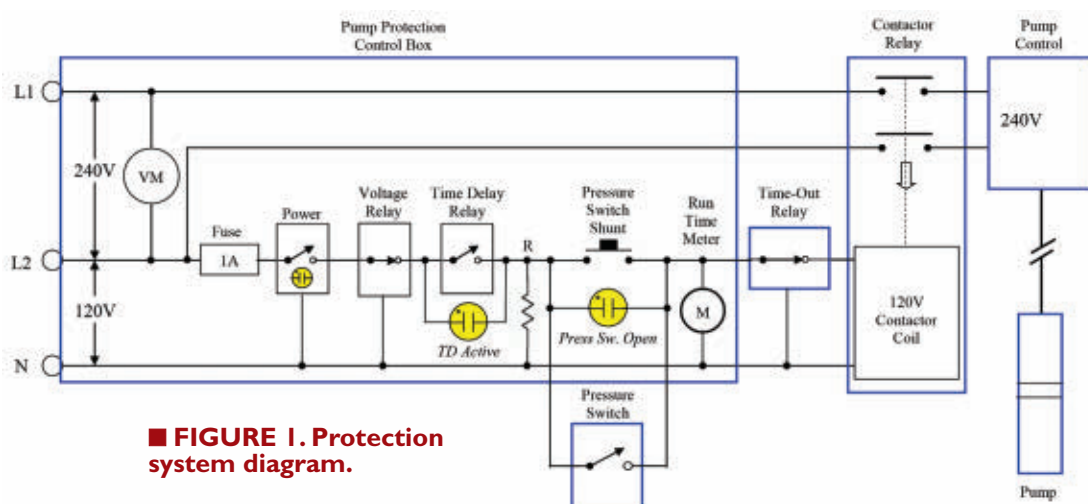
If I'm lucky, a pipe broke near our chicken coup and the leak caused my protection system to shut down the pump. It could also be the worst case scenario: The pump has failed. Not a big deal with a shallow well pump, but our pump resides 500' below ground and replacing it is an expensive endeavor. So, over the 32 years we've lived here, I've developed a system to protect the pump as much as possible. While I've employed five main protective components in the

system, readers may build their own systems employing as few as two. The system diagram is shown in **Figure 1**.

A word about safety: While the working voltage on larger submerged residential pumps is 240 VAC, all of the control circuitry on my system operates at low current at 120 VAC. The components are mounted in grounded metal cabinets with wire routing via metal conduit. There is a nearby in-view power disconnect. The control circuitry is mounted to a copper-clad board which is also grounded. While the pump is fed 240 VAC via a 15A dual breaker, all of the control circuitry runs at 120 VAC and is fused at 1A.

The Contactor (also called a Definite Purpose Starter)

The first step in taking control of your pump is to add a contactor which is shown in **Figure 2** to the right of the pump control. A contactor is really just a high-current relay, but with some added design features such as no-bounce contacts and overload protection. Those made specifically for running motors are referred to as Definite Purpose Starters. Pumps up to 2 HP are often switched directly at high current by the pressure switch, which feeds the pump control box. The diagram in **Figure 3** shows



■ **FIGURE 1. Protection system diagram.**

- **Voltage Relay:** Protects pump motor from under or over-voltage conditions. Is set to open the circuit if voltage falls below 214VAC or exceeds 254VAC. Will automatically reset when voltage is between 224VAC and 246VAC. LED on face shows ON condition. This is a 120V device, but is calibrated to act at equivalent 240V points.
- **Time Delay:** In the event of power interruption or high/low voltage cut-off, this solid-state relay stays open for 30 seconds to assure that power has stabilized.
- **Resistor R:** Acts as a load for the solid-state Time Delay relay. It is a 2.15KΩ 10W unit.
- **Pressure Switch:** Is set to 30/50# pressures, and has a mechanical cut-off at 20#. It resets itself when 24# of pressure is restored by holding the Shunt switch.
- **Run-Time Meter:** Shows total pump run time between mechanical resets. Used to show weekly run time to calculate total water use.
- **Time-Out Relay:** This relay is in its own cabinet above the contactor. It is set to cut off the pump if it runs for more than 30 minutes on a single run.

how adding a contactor allows you to isolate the pump circuit from the pressure switch.

While a standard pressure switch can handle a 2 HP motor load directly, adding a contactor will take most of the current load off the pressure switch and — most importantly — give you a low-current 120 VAC method of controlling your pump. The contactor I used also has an internal thermal over-current relay. I chose a 7A thermal



■ **FIGURE 2. Pump control (left) is powered by the contactor (right).**

unit that would trip if my 3/4 HP pump exceeded its specified current rating.

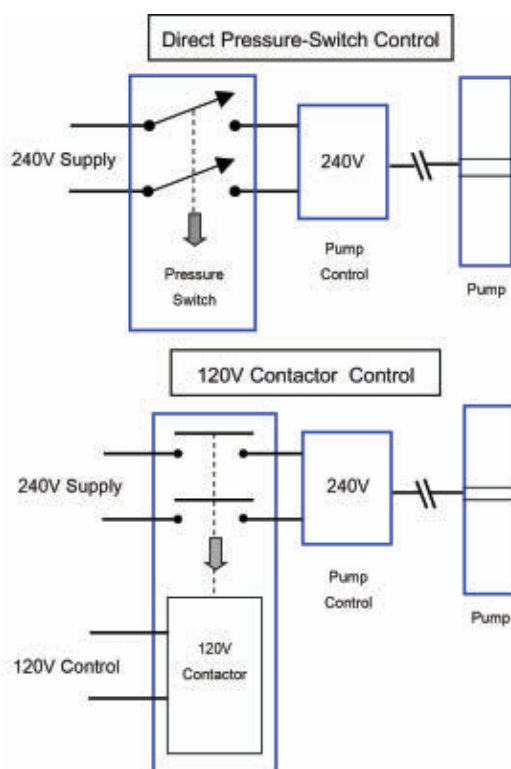
Voltage Control

I think the most important component in my system is the voltage relay. It opens the control circuit if line voltage is either too low or too high. Trying to start the pump under pressure with low voltage will likely lead to a failure; running it higher than the design voltage is almost as likely to cause a failure.

The adjustable voltage relay has hysteresis circuitry that provides a 'window' of acceptable voltages, but has a buffer above and below the set point so it won't cycle or chatter if the voltage is on either edge. **Figure 4** shows how my relay window is set to operate.

I set my trip points around 240 VAC because that is my typical line voltage. If yours is more typically 230 VAC, you may want to set lower points. I was lucky to find my SquareD® voltage relay on the surplus shelf of an electronics supply for \$10. SquareD no longer makes a 120 VAC unit, but Omron® makes a similar unit. The Omron (listed in the components list) requires a few more connections because the power supply and relay terminals are separated from the voltage measuring terminals.

The voltage relay is operating on the 120 VAC control circuit (240 VAC units are available), but measuring the AC voltage between neutral and L2 is okay. Adjusting your set points around 120 VAC corresponds to the 240 VAC line. Neutral to L1 voltage should be essentially the same



■ **FIGURE 3.** The contactor takes the place of the pressure switch.

as neutral to L2. If not, you may have a loose neutral — which can spell disaster for appliances!

Time Delay Relay

I installed a small solid-state relay following the voltage switch. Turn-on time is set via a resistor and is adjustable from three to 60 seconds. The purpose of this component is to be sure voltage has stabilized before powering the pump after an under- or over-voltage condition. When power goes out in our rural area, there are usually a few 'false starts' before it's restored.

I set this relay for a 30 second delay (with a 220KΩ resistor) to clear the usual period of fluctuation. Resistor R provides the load required for the two-wire solid-state relay to operate. I found I needed a 2.15KΩ 10W unit for a load, which draws 6.7W.

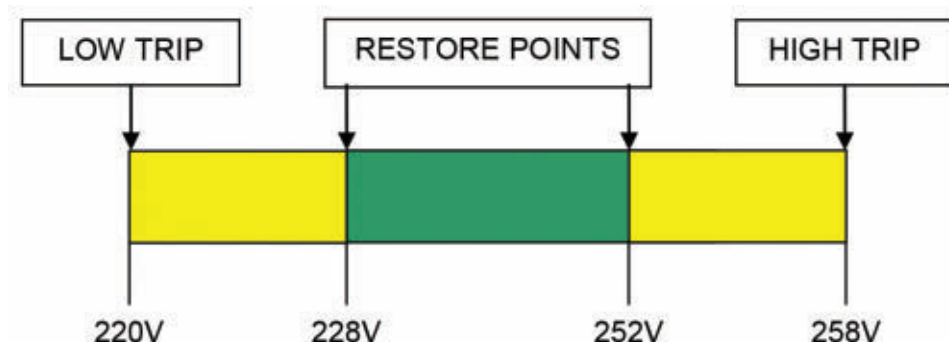
Using a three-wire relay such as the one used for the time-out function (following) negates the need for a load resistor.

Time-out Relay

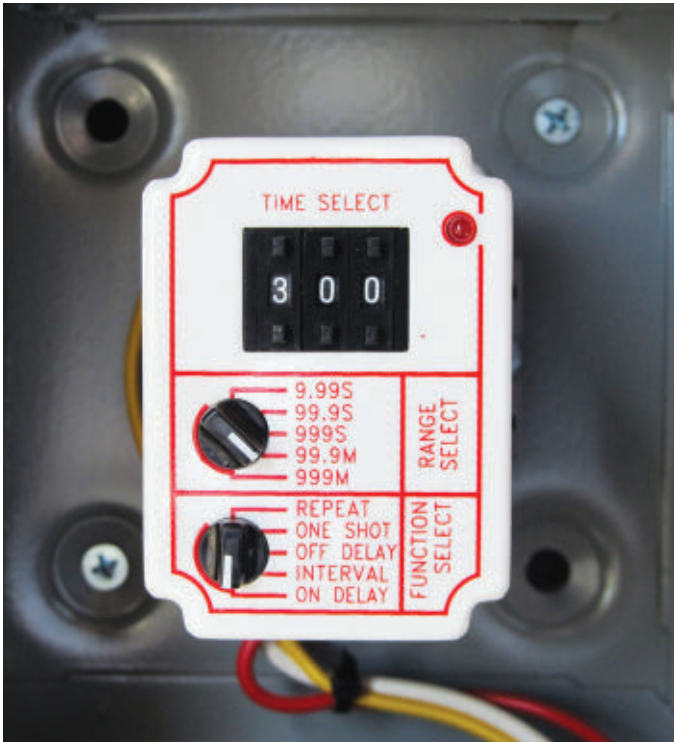
I added an outboard relay (**Figure 5**) after I found the well water very low one morning for no apparent reason. I monitor the water level with a pressurized nylon tube that I taped to the pump before lowering it into the well. The problem turned out to be a small pipe leak that the pump could keep up with, but the well could not.

As a result, the pump kept running for hours — depleting the well. The time-out relay is adjustable and I set this one at 30 minutes, which means the pump will shut down after running that long continuously.

A normal run for this pump is about seven minutes, so I only get a shut-down if there's a real problem. The time-out relay resets itself after every pump run. The relay specified in the **Parts List** is actually a time delay relay, but I'm using the NC contacts so the circuit opens (instead of closing) after a 30 minute delay.



■ **FIGURE 4.** These are the voltage points I set for my system (not to scale).



■ **FIGURE 5.** I added the time-out relay later to address slow leaks. It is set to 30 minutes.

Pressure Switch Cut-Off

The model of SquareD pressure switch I use (**Figure 6**) has a great feature built into its mechanical mechanism: a low pressure cut-off. The pressure switch keeps water pressure between 30 and 50 PSI under everyday conditions, but if the pressure drops below 20 PSI, it cuts off and has to be manually reset by restoring about 24 PSI to the system. This nicely covers the instance of a major leak like a broken fitting. Since the pump can't keep up with a big leak, the pressure drops below 20 PSI and the switch cuts off the pump. To bring the system back up to 24 PSI for the reset, I hold down the pressure switch shunt shown in the circuit diagram.

No MOVs?

While I'm a firm believer in Metal Oxide Varistors



■ **FIGURE 6.** The pressure switch now operates at low current to activate the contactor.

(MOVs) for sensitive equipment, I didn't use any here for two reasons. First, the pump is actually only connected and running about 17 minutes a day. The likelihood of a spike during that 1.2% time period is fairly slim. Secondly, the voltage relay trips within 50 ms of an overload, so it's likely to catch a major spike.

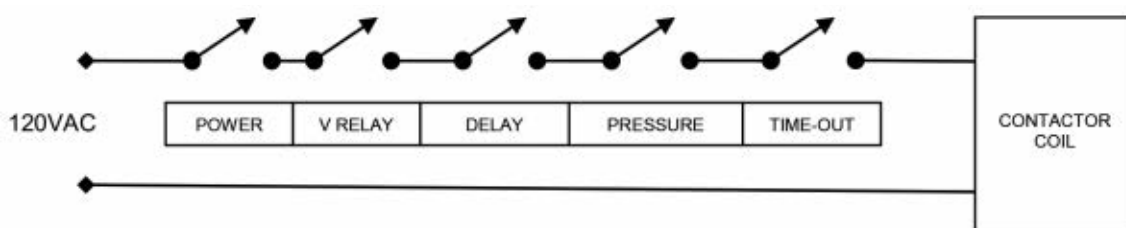
If we are in the midst of a lightning storm, I'll check the water pressure to assure myself that the pump is not going to run during the storm. If it's close to the 30 PSI pump start, I'll just shut off the control switch. While the contactor will still have 240 VAC on its contacts, they can't close with the control circuit shut down.

The Circuit

As you look at the circuit diagram, you can think of each sequential component as an SPST switch. All five 'switches' are effectively wired in series (**Figure 7**) and all

ITEM	DESCRIPTION	SOURCE
Voltage relay	Omron K8AK-VS2 100-240VAC	Mouser Electronics 653-K8AKVS2100240VAC
Contactor	Square-D 8911DPSG12V02	Grainger 11V704
Contactor Thermal Unit	Depends on pump current	Grainger 1H640 for 5.8A-7.7A loads
Pressure Switch with Low-Pressure Cut-Off	Square-D 9013FSG-2J21M4	Grainger 2FH06
Time-Delay Relay	Amperite 120A1-100SST1	Newark 28B910
Time-Out Relay	Dayton 6A855	Grainger 6A855
240 VAC Voltmeter	Shurite 8407Z	Newark 48J6230

**PARTS
LIST**



■ **FIGURE 7.** This is the equivalent circuit of all the components.

have to be closed to operate the pump. If the pump is not running, I can look at the indicators to see what's open. Most often it would be the pressure



■ **FIGURE 8.** The front panel of the protection system.

switch, if pressure is between 30 and 50 PSI.

When I first power up, the Time Delay Active light illuminates for the 30 second delay. I used neon lamps for indicators mainly because I already had the sockets in my parts collection.

I added a few extra items to the front panel (**Figure 8**) for my own purposes. The 240 VAC meter on the lower left assures me that I'm getting full voltage from my service entrance (100' away) when the pump is operating. If I need to use my generator to run the pump, the meter lets me monitor the voltage from inside the well house. The pressure switch shunt (center above the voltmeter) allows me to run the pump manually up to the 24 PSI restore point for the pressure switch. I can also check pump current (at the pump control) by manually running the pump.

The resettable run time meter (top left) lets me know how much water we use every week. Since the pumping rate averages 4.5 gallons per minute (GPM), I can simply multiply the minutes of running time to log total use. It is typically around 550 gallons per week for my wife and me, along with three dogs, four cats, three hens, and a goose. We also have an efficient drip system for our trees and plants. Relying on your own well makes one very conscious of water use.



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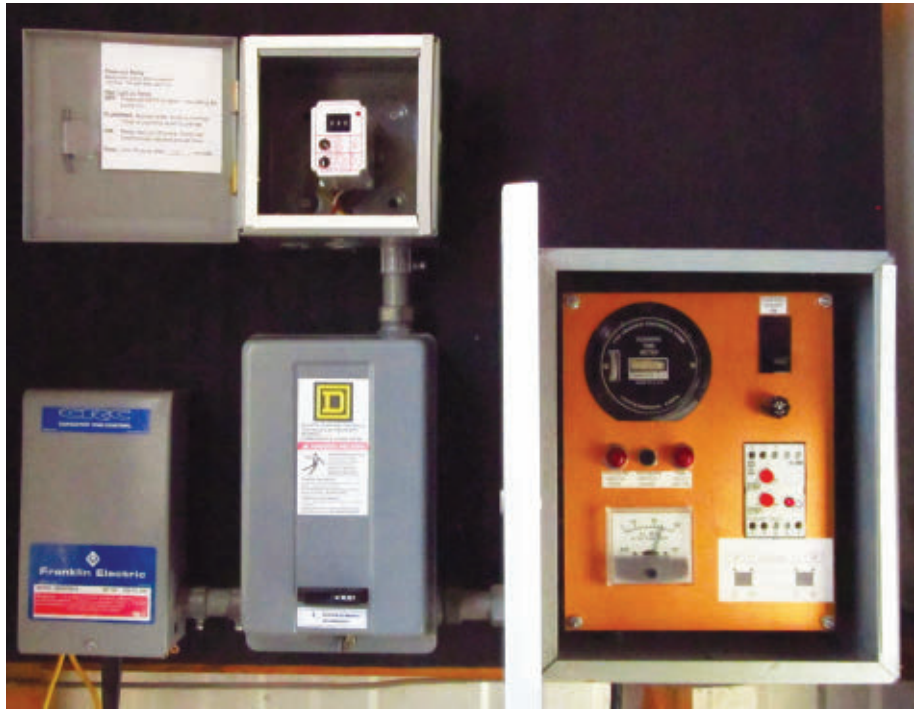
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Conclusion

The completed pump protection system (**Figure 9**) has operated reliably for 15 years and, while I can't really tell how many times it may have saved the pump, it's good to know that it has constant protection. If a reader would like to build a more basic system, I would recommend using at least the voltage relay and contactor.

Since various pump systems require different voltages and currents, equipment shown in the **Parts List** may not fit all needs. Parts listed work well for my 240 VAC 3/4 HP pump, but the appropriate contactor will handle higher loads. The contactor in my system is rated for 20A, or 3 HP at 240 VAC. The 120 VAC control circuitry shown in the article should operate any contactor with a 120 VAC coil.

I hope this project can serve you well. **NV**



■ **FIGURE 9.** The completed system.

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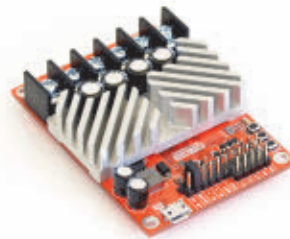
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Adjustable Electronic Load Using INCANDESCENT LAMPS

By Paulo Oliveira

Post comments on this article and find any associated files and/or downloads at www.nutsvolts.com/magazine/article/July2016_Adjustable-Electronic-Load-Using-Light-Bulbs.



The humble incandescent light bulb doesn't get much respect anymore. Facing extinction in many countries and being replaced by more modern and efficient alternatives like LEDs, the uses for these incandescent lamps are few these days. The long time electronics hobbyist (like me) is often left with drawers full of bulbs with no obvious use for them. And yet, for all their failings and inefficiencies, incandescent lamps still hold a nostalgic place in the heart of many electronics hobbyists who still love the soft warm glow of a light bulb. Can we save them from their fate and give them a new life?

This is the story of how I saved some of my light bulbs from extinction by building a useful lab tool with them: an adjustable electronic load.

The Need for Adjustable Electronic Loads

An adjustable electronic (power) load is a very handy piece of test equipment in the development of electronics projects. For example, when you are building a power supply, there will come a time when you need to “simulate” a load to see how well your design performs. To properly test a power supply, an adjustable load is just the ticket. It allows you to measure how much current the supply can deliver at a given output and input voltage, and measure important parameters such as efficiency, regulation, and ripple under various load conditions.

In the old days, I sometimes would use an incandescent light bulb as a crude power load when testing a power supply. Light bulbs were easy to find and could draw a lot of current — which is actually an advantage in this application. However, I would often be limited by the choice of light bulbs available at hand.

Controlling the amount of current drawn from the supply under test was a trial-and-error affair at best. Then, it occurred to me: What if I could make a sort of “variable incandescent DC load?” This would be a very useful tool for me, and I would use my long abandoned incandescent lamps ... a win-win situation!

Traditional versus PWM Adjustable Loads

There are a few different ways to build an adjustable electronic load. A traditional approach (and one that I built myself in an earlier project [1]) uses one or more power MOSFETs in parallel as load element(s). The top diagram in **Figure 2** shows a simplified version of this traditional arrangement. By adjusting the MOSFET’s gate voltage (typically with a DC signal), the MOSFET resistance from Drain to Source changes so you effectively get an adjustable load (resistance) from the “INPUT” perspective.

Note that in these types of circuits, the MOSFETs dissipate most of the power and heat, and thus need to be fitted with adequate heatsinks. You might even need cooling fans. (The circuit may also require a power sense resistor if some sort of feedback loop or measurement is implemented, but I will stick to an open loop strategy here for simplicity’s sake.)

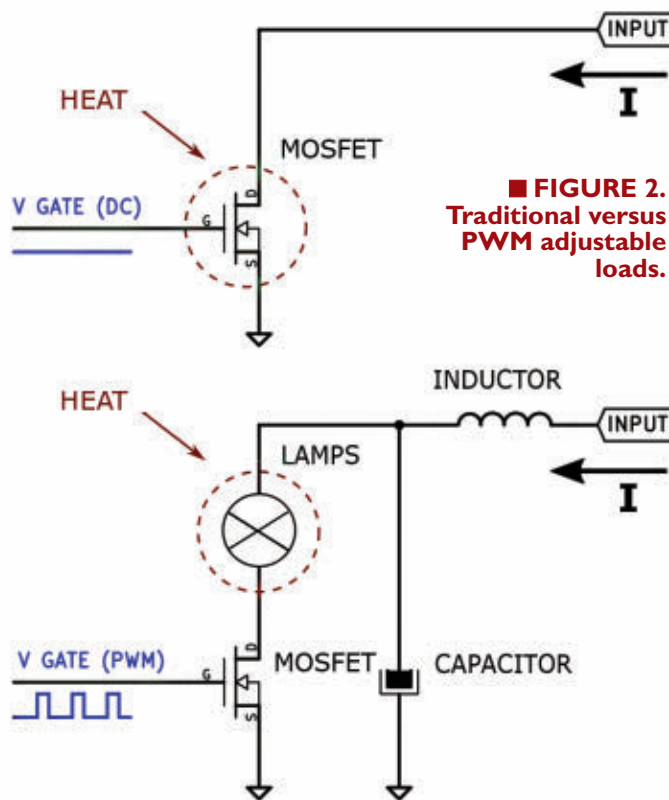
The bottom circuit in **Figure 2** shows the strategy I employed instead. The incandescent lamp(s) are placed in series with a MOSFET. Rather than applying a DC control circuit to the gate, I applied a variable duty cycle PWM signal. As the duty cycle increases, so does the average



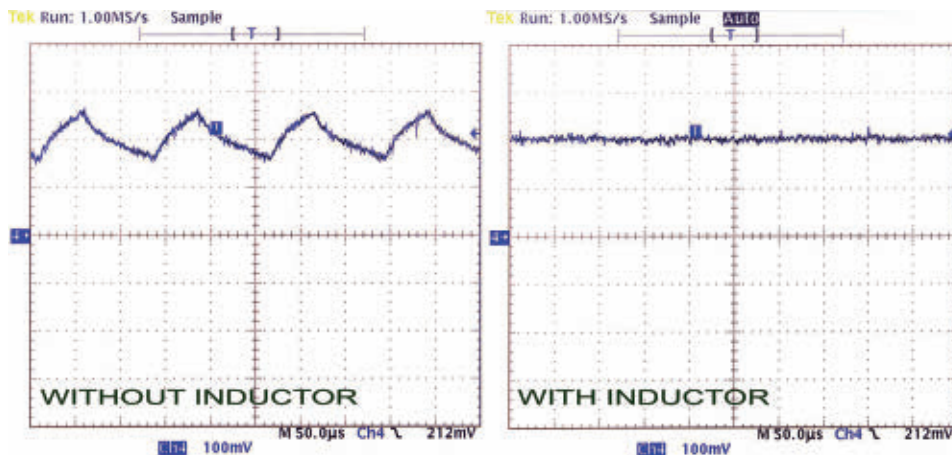
■ **FIGURE 1.** Incandescent light bulbs.

current through the lamps, so you get — in effect — an “adjustable load.” However, this wouldn’t be a very useful circuit if we didn’t filter the abrupt changes in current from the load as the MOSFET turns ON and OFF. This is the function of the series inductor and capacitor in the figure which form an LC low-pass filter. These components are absolutely crucial here.

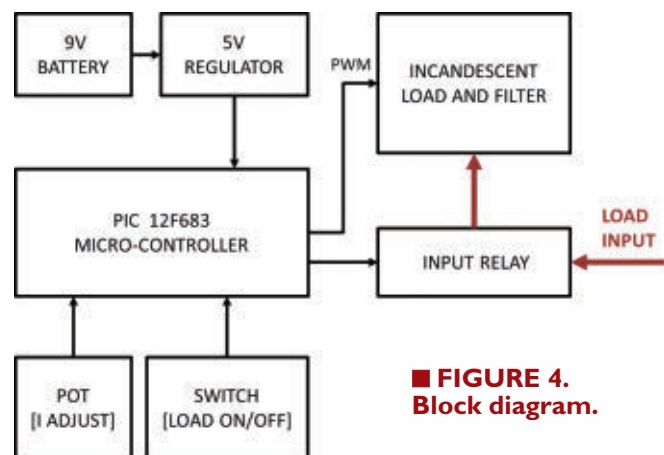
To illustrate this, I measured the current through this circuit with and without the series inductor using a small



■ **FIGURE 2.** Traditional versus PWM adjustable loads.



■ FIGURE 3. Load current with and without inductor.

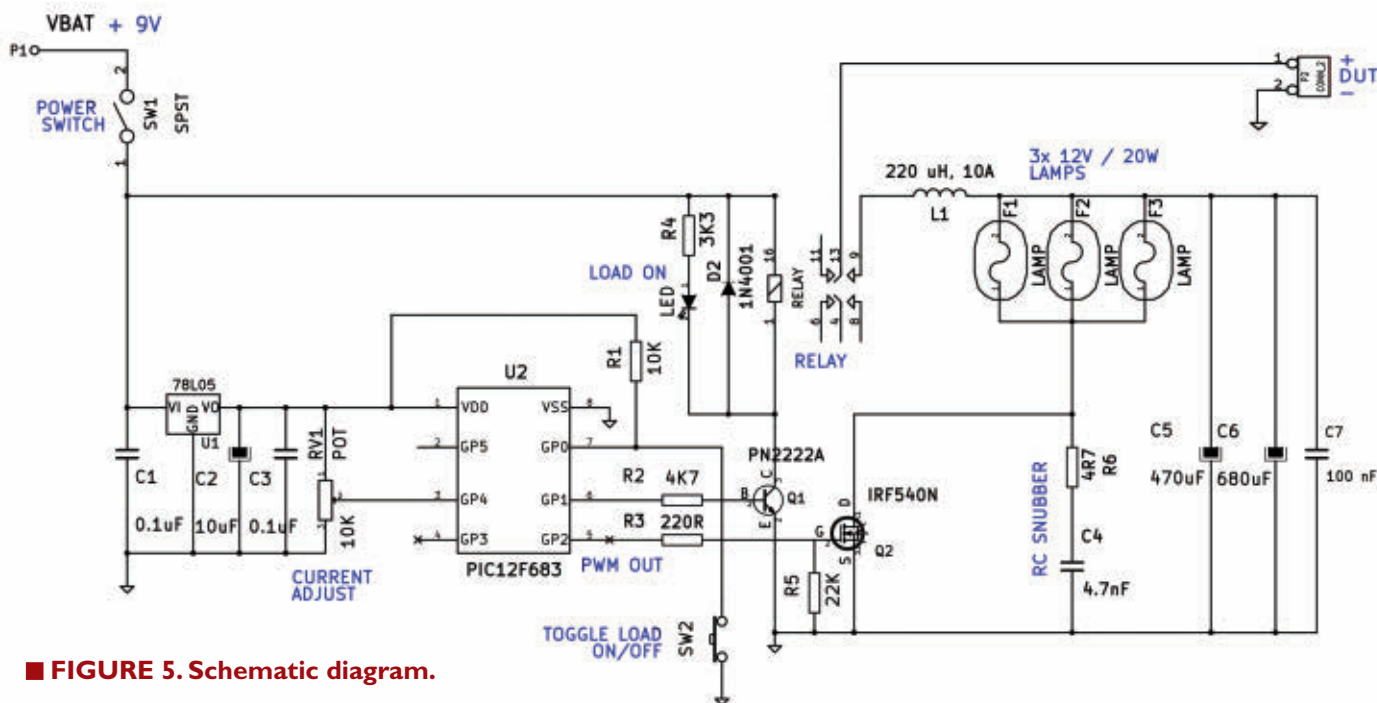


■ FIGURE 4. Block diagram.

appreciable ripple, which is our goal.

It's important to note that – unlike in the traditional approach – most of the heat in this circuit is dissipated in the incandescent lamps instead of the MOSFET. Since the MOSFET is either turned OFF (close to infinite resistance) or turned ON (close to zero resistance), the power dissipated in the device is much lower than with the traditional circuit. The incandescent lamps do the heavy lifting here and dissipate most of the heat. Plus – unlike the MOSFETs – incandescent light bulbs do not need large heatsinks!

Furthermore, you get visual indication that the current is flowing through the lamps, which I find is satisfying and advantageous user feedback in this sort of test equipment.



■ FIGURE 5. Schematic diagram.

Circuit Diagram

Figure 4 shows a block diagram for the circuit, whereas **Figure 5** shows a schematic diagram. An eight-pin PIC12F683 microcontroller (U2) is used to provide the PWM signal to the gate of the MOSFET. The internal ADC (Analog-to-Digital Converter) reads a voltage from a multi-turns potentiometer (POT) and adjusts the PWM duty cycle proportionally. You could instead use two potentiometers in series (one for 'coarse' adjustment and another for 'fine' adjustment), but I find the multi-turns potentiometer provides a better user experience in practical use.

One drawback of incandescent bulbs is that they are non-linear devices; as the current changes, their resistance varies dramatically. This is why it's important to have a good resolution PWM signal (10-bit in this case) and a multi-turns

potentiometer so you can precisely control the circuit over the wide range of selectable load currents.

I also added a pushbutton (SW2) connected to the microcontroller that toggles the load ON and OFF every time the user presses it. The microcontroller detects when the switch is pressed and controls a relay in series with the load accordingly (the software defaults to having the load OFF when the circuit is first powered). This feature is useful when you want to quickly disconnect the load; say, in an overload condition.

Since I wanted the adjustable load to be portable so I can easily move it around my lab bench, I decided to use power through a 9V battery. A 78L05 linear regulator (U1) converts the battery voltage to the 5V needed by the microcontroller.

The corresponding schematic for my final circuit is shown in **Figure 5**. I used three incandescent light bulbs of the type you find in car brake lights and connected them in parallel (more on lamp selection later). These light bulbs can handle large currents and are designed for voltages around 12V, though I was able to drive them with voltages up to 20V without problems.

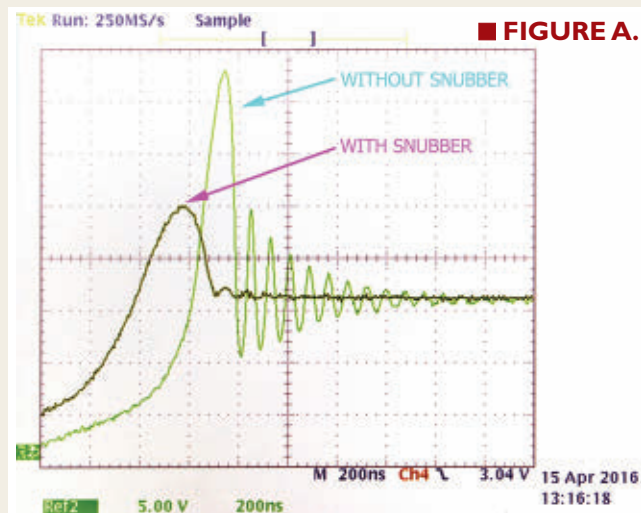
The power MOSFET I chose for this circuit (Q2) is the IRF540N which has very low ON resistance (about 44 m Ω), so it dissipates little power when turned ON. The IRF540N has a gate threshold voltage below 4V, so it can be driven directly by the 5V microcontroller with only a series resistor (R3) to limit the input current and edge rate.

RC Snubber

A common issue when quickly switching a power MOSFET is that it can result in significant noise and ringing when the MOSFET turns ON/OFF abruptly. This is caused by the parasitic inductance and capacitance in the circuit which forms an RLC tank circuit that is — in effect — responding to a 'step' input. To minimize the resulting VDS (Drain to Source) voltage spikes and oscillations, one can place an RC snubber across the MOSFET Drain and Source pins.

Figure A shows the VDS transient voltage spike I measured with and without the RC snubber formed by R6 and C4. While there is still some room for optimization here, you can see that the voltage spike peak is significantly reduced and so is the oscillatory behavior. RC snubbers protect the MOSFET from over-voltage and reduce noise that could otherwise couple to sensitive circuits connected to this load.

For more information, please refer to Reference [2].



Pull-down resistor R5 ensures the MOSFET is OFF by default.

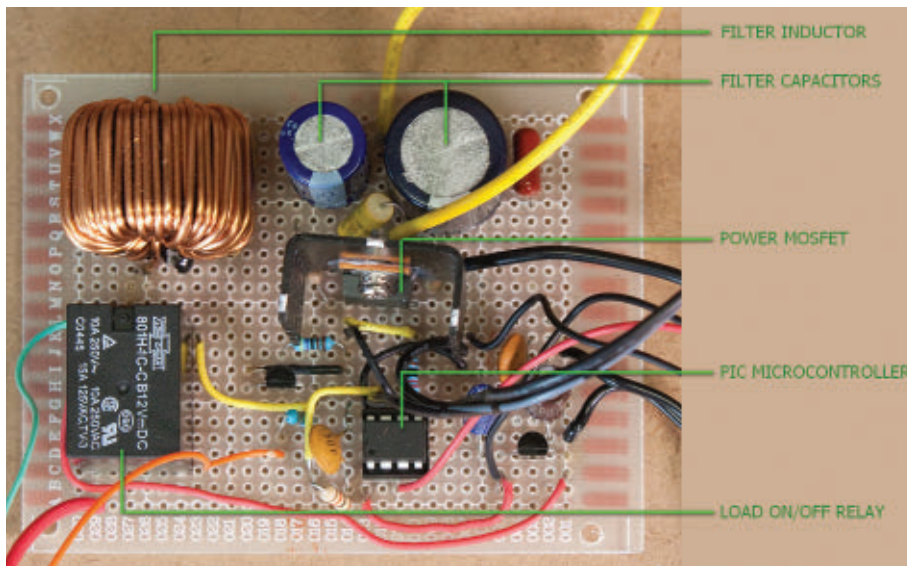
The microcontroller's GP1 output controls a 2N2222 transistor (Q1) that, in turn, activates the relay coil connected to the 9V supply. It also turns ON an LED to signal the user that the load is connected. Diode D2 protects the transistor from inductive 'kick-back' voltages.

I used three different capacitors in parallel (C5, C6, and C7) in an effort to reduce the Equivalent Series Resistance (ESR) over a wide frequency range. Low ESR is important in this application for effective low-pass filtering and to reduce the heat dissipated in the electrolytic capacitors themselves (which could lead to failures over time).

The RC snubber circuit formed by R6 and C4 reduces the voltage spikes and noise generated when the MOSFET switches ON and OFF (see the **sidebar**, RC Snubber).

Incandescent Light Bulb Selection

In this project, I reused automotive brake lights that I already had in my parts bins. However, for those who don't already have them handy, these light bulbs are easy to find in any automotive parts store. Light bulbs for automotive applications are physically small (relative to the power they can handle), and are also relatively inexpensive. Any 12V, 20W, to 50W bulbs should be



■ **FIGURE 6. Assembled perf board circuit.**

adequate. The choice rests mostly on the maximum current you need to draw for the supply voltages you plan to test. The higher the light bulb power rating, the higher the current you will be able to draw in your load.

For example, a single 20W 12V bulb would nominally draw about $20/12 = 1.67\text{A}$ at 12V. This circuit allows you to draw *less* current than this by adjusting the

during operation, and include a way to enclose them so the risk of accidental contact is minimized.

Construction

As this is a relatively simple circuit using only through-hole components, I decided to build it using a prototype

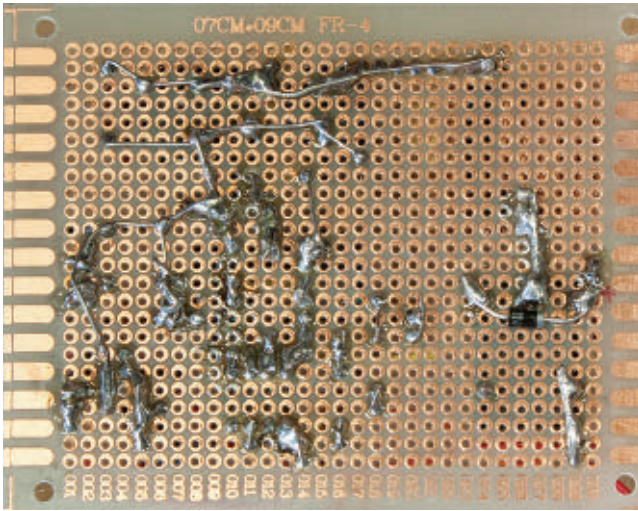
potentiometer, but not *more* current. This is why I paralleled three bulbs as I wanted to draw at least 4A maximum at 12V (and I had quite a few unused bulbs available). However, if you don't routinely need to test supplies with this much current, you may only need one or two bulbs.

You should also be careful not to burn the light bulbs by applying voltages above their rating (above 12V in this case) for extended periods of time while drawing maximum current. You can always place more bulbs in series if this is a requirement for you, or use 24V bulbs instead.

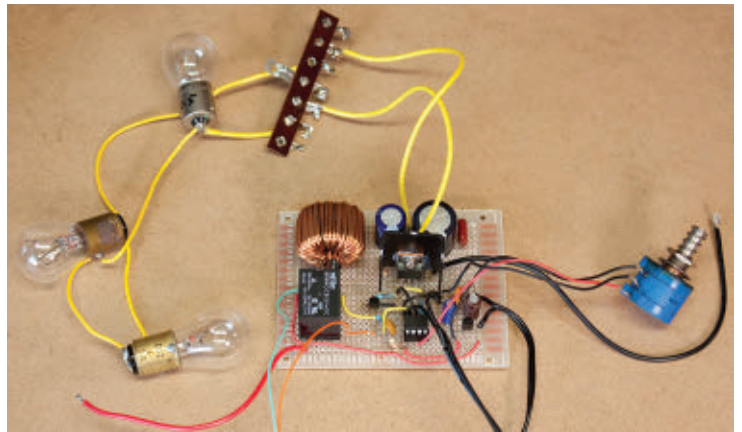
Safety Warning: Incandescent light bulbs get very hot and can burn you! Make sure you don't touch the bulbs

ITEM	DESCRIPTION	SOURCE
ACTIVE COMPONENTS		
U1	78L05 5V Linear Regulator	Digi-Key LM78L05ACZFS-ND
U2	PIC12F683 Microcontroller	Digi-Key PIC12F683-I/P-ND
Q2	N-Channel Power MOSFET	Digi-Key IRF540NPBF-ND
Q1	2N2222 NPN Transistor	Digi-Key PN2222AFS-ND
D2	1N4001 Diode	Digi-Key 641-1310-1-ND
D1	Red LED	
RESISTORS — 1/4W 5% axial carbon film		
R1	10K	
R2	4.7K	
R3	220R	
R4	3.3K	
R5	22K	
R6	4.7R	
CAPACITORS		
C1	0.1 μF / 100V Ceramic	
C2	10 μF / 16V Electrolytic	
C3	0.1 μF / 100V Ceramic	
C4	4.7 nF / 100V Film	
C5	470 μF / 50V Electrolytic	
C6	680 μF / 50V Electrolytic	
C7	0.1 μF / 100V Ceramic	
MISCELLANEOUS		
L1	Toroid Core Inductor 220 μH , 4A or higher	eBay http://tinyurl.com/zmoutld
RELAY	SPDT 10A Relay	Digi-Key 255-2065-ND
RV1	10K Multi-turns Potentiometer	eBay http://tinyurl.com/zoqs4ru
Perf Board		
Light Bulbs	(see text)	Automotive parts store

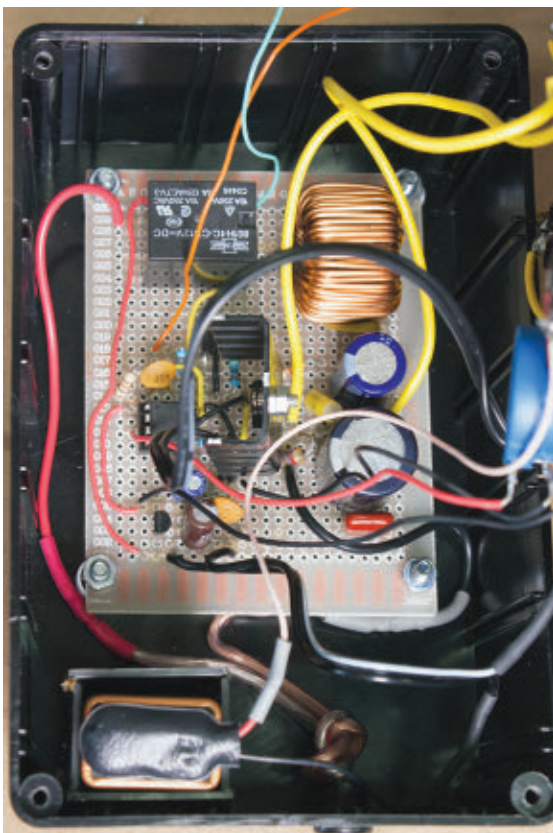
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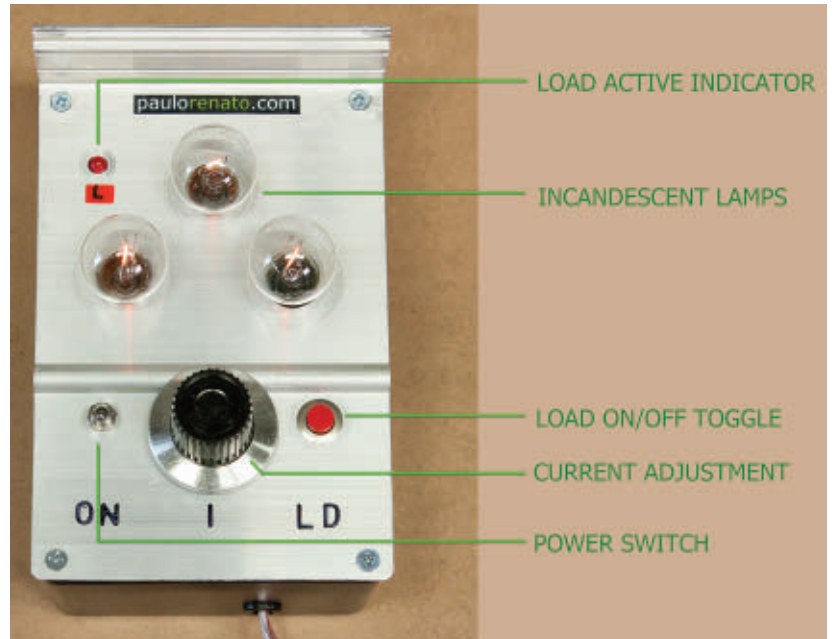
■ **FIGURE 7.** Back of the board.



■ **FIGURE 8.** An early prototype.



■ **FIGURE 9.** Circuit inside a small plastic enclosure.



■ **FIGURE 10.** Front panel with controls and indicators.

board (a.k.a., perf board). **Figure 6** shows an overhead view of the assembled perf board circuit and highlights the main components. Even though the MOSFET I used doesn't dissipate the bulk of the power (the light bulbs do), I did equip it with a small heatsink as it can get slightly hot when drawing high currents (in excess of 3A).

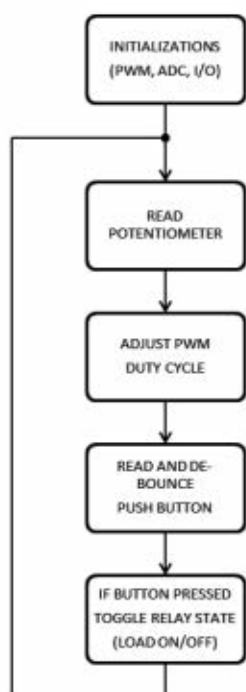
Figure 7 shows the underside of the board. Pay close attention to the portions of the circuit where the potentially high load current flows (this is the portion of

the circuit represented in the bottom of **Figure 3**). Make sure the wire gauge is thick enough to handle the current through these paths. It also helps to re-enforce (with solder) the high current flow paths as this lowers overall electrical resistance. Also try to keep these connections as short as possible.

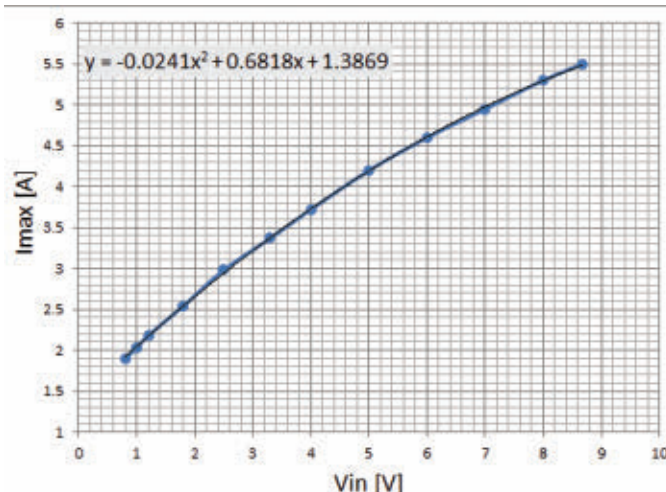
Figure 8 shows an early prototype as it was before I committed the circuit to a proper enclosure. Here, you can see the multi-turns potentiometer and the three lamps connected to the main board.

Figure 9 shows the circuit inside a small plastic enclosure. Notice the 9V battery mounted on the bottom left portion of the box.

Figure 10 shows the final product front panel and highlights the main controls and indicators.



■ **FIGURE 11. Program flowchart.**



■ **FIGURE 12. Maximum current versus input voltage.**

Software

The PIC runs software developed using the the M.E. Labs, Inc. (formerly microEngineering Labs), PICBASIC PRO® compiler. The complete code can be downloaded from the article link. Both source code and compiled files are available. If you own a PIC programmer and don't need to make any changes to the code, then you can simply program the PIC using the .hex file without need to recompile the code.

The flowchart in **Figure 11** shows the program structure. It starts by defining some constants and performing block-level initializations.

The internal ADC is connected to the GP4 input and set for 10-bit mode. The PWM is initialized and also set for 10-bit mode so that its resolution is maximized and matches the ADC resolution. As noted earlier, this resolution is important for precise control over a wide range of load currents. Unfortunately, there is a tradeoff between resolution and PWM frequency in this microcontroller (which is not uncommon).

Because of this tradeoff — while I would have preferred using a PWM frequency above 40 kHz as it would have made the LC filtering easier — I ended up setting it to about 8 kHz. With the inductor and capacitor values used, though, this switching rate is high enough for effective filtering.

In the main body of the program, we enter a main loop which starts by reading the ADC voltage (connected to the potentiometer). For the ADC reading, I decided to

take eight samples and discard the edge samples to avoid issues with noise. This is done by sorting the eight samples and then averaging only the inner samples (you could call this a “trimmed mean”). The resulting (filtered) value is then used to adjust the PWM duty cycle proportionally to the potentiometer/ADC voltage reading.

Next, the program polls the toggle switch input to detect if it has been pressed. Note that there's debouncing code executed here to avoid instability. If the switch press is detected, the relay output is toggled and the load turned ON (or OFF).

Results

With the three paralleled light bulbs I used, I was able to draw in excess of 3A at 3.3V and north of 4A with a 5V supply input. This is more than adequate for most of my uses. As I explained under “Incandescent Light Bulb Selection,” the *maximum* current one can draw with this adjustable load is determined by the light bulb's power rating and changes in a non-linear fashion with voltage.

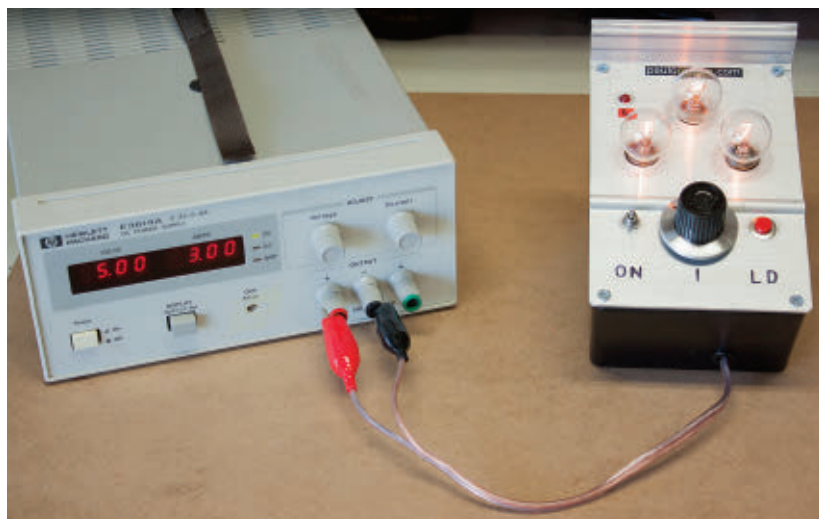
For the reader's reference, I plotted my measured “maximum current versus input voltage” graph in **Figure 12**. I overlaid a trend line (using Microsoft® Excel) and associated equation that allows the user to estimate the maximum current for voltages other than the ones I measured.

Note that this curve would be different if different light bulbs were used, and represents only the *maximum* current the load is capable of drawing at each input voltage. Lower currents — from zero up to the maximum — are obtained by simply adjusting the potentiometer.

Conclusions and Future Improvements

While I'm quite satisfied with the current implementation and it has already proven very useful in my hobby, there is always room for improvement in any project. Here are some thoughts for future improvements that the reader may consider:

Gate drive — For high power operation, level shifting the MOSFET gate drive to 9V would result in higher VGS voltage, thus lower on resistance and potentially even less power dissipated in the MOSFET. This should be considered if very high load currents are needed.



■ **FIGURE 13.**
Adjustable
load in action.

PWM frequency — If the reader uses a different microcontroller or even a dedicated PWM circuit, then you might be able to increase the PWM frequency to 40 kHz or higher. This should improve filtering and/or allow you to use a smaller inductor for the same current ripple.

In-rush current limiter — One drawback of incandescent lamps is that their resistance when cold is much lower than in “normal” operation (a factor of 10 times is often mentioned as a rule of thumb). This low ‘cold resistance’ results in a current spike (overshoot) when you first connect the load to a supply under test. While this hasn’t been a significant issue for my purposes, it is something the reader should be aware of as it could (in some cases) trigger over-current protection circuits in the supplies under test.

Adding a small series resistor or even a more complex start-up only current-limiting circuit could improve this situation. For example, you could add another relay controlled by the same microcontroller that keeps a series resistor in-circuit for a few milliseconds following load activation, and then shorts them for steady state operation.

This project has been a rewarding one, not only because it proved very useful on my workbench but also because it allowed me to rescue and repurpose some of my old incandescent

light bulbs. I do enjoy seeing the visual feedback provided by the light glow as current traverses the circuit (see **Figure 13**).

This is a somewhat unique feature you don’t get with MOSFET based approaches; it’s similar to looking at a good old tube amplifier versus a modern transistor amplifier. Hope you enjoy yours, too. **NV**

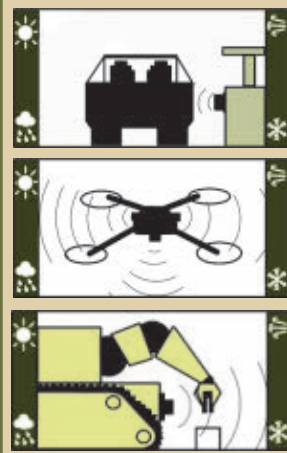
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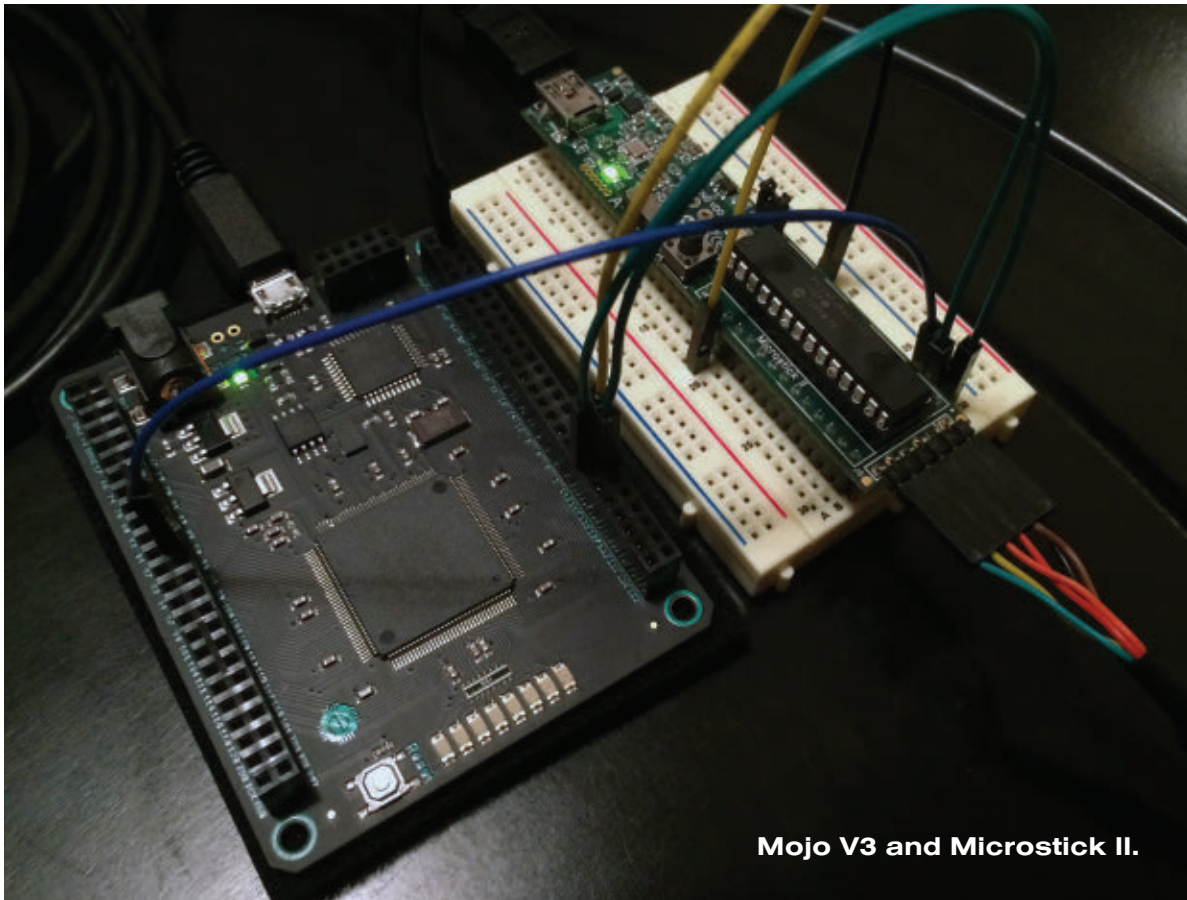
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Open source software has become increasingly popular with hobbyists, businesses, and governments for various reasons, whether it's the transparency of the software, the inherent security advantages, or simply the fact that a lot of open source software is free. Lately, this trend has gained traction in the electronics hobbyist community with open source hardware. In an article I did back in the July 2015 issue, I introduced you to the open source Mojo V3 FPGA development board from Embedded Micro. In this article, I will discuss how to use open source hardware IP-cores from OpenCores.org on that device.

What is OpenCores.org?

OpenCores.org is the leading website related to open source hardware IP (intellectual property) cores for FPGAs (field programmable gate arrays). On the site are hundreds of downloadable IP cores ranging from simple memory modules to a fully functional Amiga Original Chip Set System on Chip (SoC) incorporating the Wishbone Bus. The site does require you to create an account in order to download IP-cores from their SVN repositories, but the process is relatively simple and they also provide you with a free email alias.

Of course, just like open source software, the quality of the open source IP cores can be very different. While some cores may be wonderfully documented with full support from their authors, others are barely functional with the user left guessing how it works, if at all! As with anything free on the Internet, your mileage may vary.

The challenge of using a third-party IP core is how to integrate it into your chosen FPGA platform. The goal of this article is to take a fully functional and complete core from **OpenCores.org** and integrate it onto the Mojo V3 development board. Let's get started!

What Should We Create?

While the allure of the Amiga SoC is strong, we should probably start with something a little more tangible and a bit simpler to test and verify. How about a 16 x eight-bit SPI serial ROM, you say? Okay!

In order to interface with and test this ROM, I used a Microchip PIC24FJ64GB002 microcontroller installed on the Microstick II development board. Why not an Arduino, you ask? Well, the Arduino Uno R3 I own is a 5V device and the Mojo V3 is a 3.3V device.

Additionally, I prefer PICs, and frankly, I've been waiting for an excuse to use the Microstick II in a project. Feel free to use any other platform that is 3.3V compatible.

Our SPI serial ROM will use all four of the standard SPI signals (SCK, MOSI, MISO, and SS). The ROM will output the data stored at a saved ROM *read* address and subsequently increment that saved address upon the completion of each SPI transfer. It will also respond to a single command which will set the saved ROM *read* address for a subsequent *read* operation. This should be fairly simple to design, so let's get on it!

Prior Planning Before Execution

First, let's take a look at the actual ROM (`rom_16x8.v`). The signals for the ROM are as shown in **Table 1**.

Table 1.	
SIGNAL	DESCRIPTION
<code>clk</code>	Master Clock
<code>addr</code>	Four-bit Address
<code>data</code>	Eight-bit Data

I've designed it as a synchronous ROM, and stored a classic and appropriate message inside. Of course, that message would be, "Hello, World!" There really isn't much more to say about such a simple module, so let's move on.

Poking around **OpenCores.org**, I found a very well constructed SPI core which includes both master and slave modules. The core — titled *SPI Master/Slave Interface* — was designed by Jonny Doin and is listed as stable. The overview page for the project is detailed and has screenshots of waveforms showing how the master and slave modules function. Perfect! This is a great example of an above average IP core on **OpenCores.org**.

Of note, the source for the *SPI Master/Slave Interface* is written in VHDL. Our project is written in Verilog. However, even though you may not know VHDL (such as myself!), it is easy to integrate modules written in different HDLs (hardware description languages).

Let's take a look at the source code available at the article link for the SPI slave (`spi_slave.vhd`). The comments are thorough and do a nice job outlining how

Table 2.	
SIGNAL	DESCRIPTION
<code>clk_i</code>	Master Clock
<code>spi_sck_i</code>	SPI Clock
<code>spi_mosi_i</code>	SPI Master Output/Slave Input
<code>spi_miso_o</code>	SPI Master Input/Slave Output
<code>spi_ssel_i</code>	SPI Slave Select
<code>di_req_o</code>	Input Data Request
<code>di_i</code>	N-bit Input Data
<code>wren_i</code>	Input Write Enable
<code>wr_ack_o</code>	Input Write Acknowledge
<code>do_valid_o</code>	Output Data Valid
<code>do_o</code>	N-bit Output Data

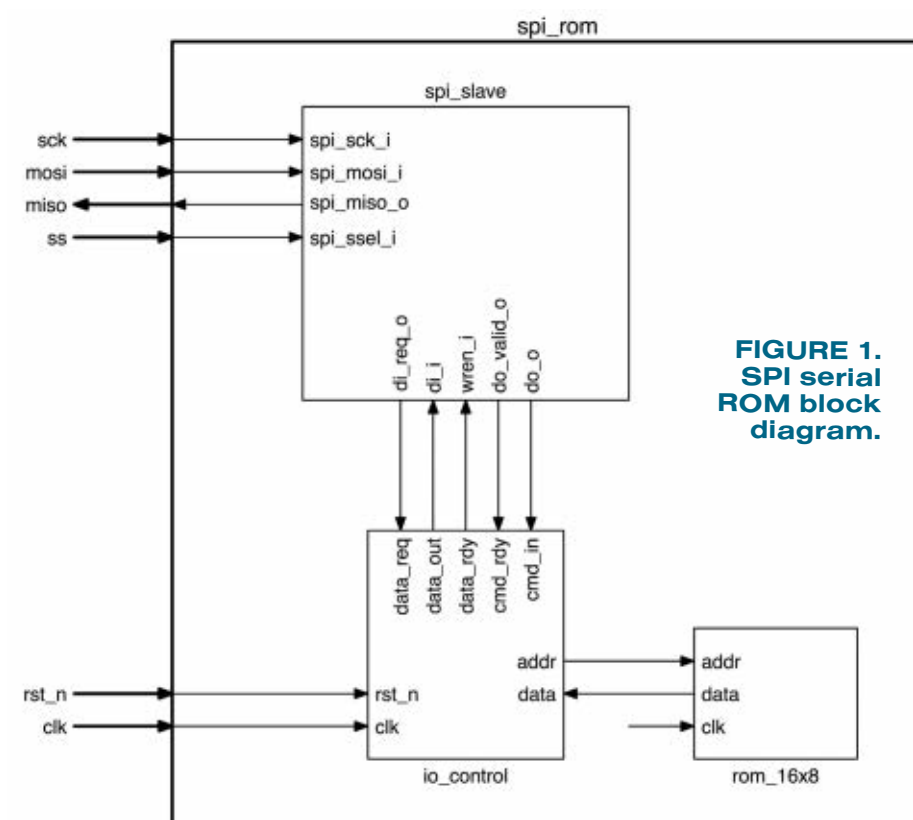


FIGURE 1.
SPI serial
ROM block
diagram.

the module works. The module accepts four parameters: word length (*N*); clock polarity (*CPOL*); clock phase (*CPHA*); and pre-fetch look-ahead (*PREFETCH*). Additionally, the module has 11 different signals to cover SPI *read* and *write* operations that are shown in **Table 2**.

Before we move forward, I need to clear up a potential point of confusion. When it comes to the SPI slave module, the input data (*di_i*) is what we want to send to the master (*MISO*). The output data (*do_o*) is what we have received from the master (*MOSI*).

This is important to remember, as it can lead to problems later if it is still confusing. (This may or may not have happened to me.)

It is clear that we will need an I/O control module (*io_control.v*) to interface between our ROM and the SPI slave. As discussed previously, this I/O control module will handle the command decoding and store the ROM *read* address. The I/O control

Table 3.	
SIGNAL	DESCRIPTION
clk	Master Clock
rst_n	Asynchronous Reset (Active Low)
data_req	Data Request from SPI Slave
data_ack	Unused
cmd_rdy	Input Data Received from SPI Slave
cmd_in	N-bit Input Data from SPI Slave
data_out	N-bit Output Data to SPI Slave
data_rdy	Output Data Ready for SPI Slave
addr	Four-bit ROM Address
data	Eight-bit ROM Data

Table 4.		
data_req_reg	data_req	data_req_edge
0	0	0
0	1	1
1	0	0
1	1	0

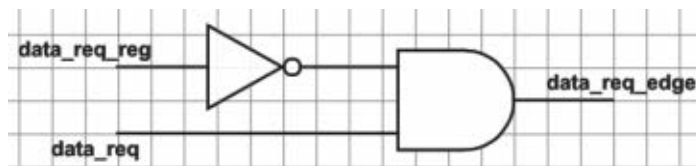


FIGURE 2. Edge detector logic.

module accepts a single parameter for word length (*N*) and has the signals shown in **Table 3**.

Okay, that should cover everything. **Figure 1** shows how all the pieces are tied together. As you can see, the top-level module (*spi_rom.v*) has six signals. The standard SPI signals are wired directly to the SPI slave module, and the clock and reset signals are wired to the I/O control and ROM modules. Pretty simple!

How Does This Work?

Don't worry, I wasn't going to leave you hanging. Let's talk about how the I/O control module functions, which is the brain of the SPI serial ROM. At its core, the I/O control module has two registers: one for the SPI slave data request signal and one for the ROM *read* address.

The data request register is used as a positive edge detector for the *data_req* signal. Normally, the data request signal is low. However, if the SPI slave module requires data, it will send a pulse to the I/O control module which is two clock cycles long, as shown in the SPI slave source (*spi_slave.vhd*). The logic for the edge detector is basic and is shown in **Figure 2**. The truth table

Table 5.							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Command				Address			

is shown in **Table 4**.

We can't very well talk about decoding a command without first discussing our command format. The I/O control module will accept an eight-bit byte in the format as in **Table 5**.

As you can see, the upper nibble is the command and the lower nibble is the ROM read address. The module will respond to only one command – 0x1 – which sets the ROM read address as discussed earlier.

So, how do we decode a command? First, the module checks if a command has been received (`cmd_rdy`). If it has, we verify that the upper nibble is equal to 0x1. If it is, we transfer the address stored in the lower nibble of the received command to the ROM read address register in the module. Pretty easy, right? However, there is one catch.

How do we respond to subsequent read operations? If a command is not ready and the SPI slave module is requesting more data (`data_req_edge`), then we will increment the ROM read address register by one. The logic diagram is shown in **Figure 3**.

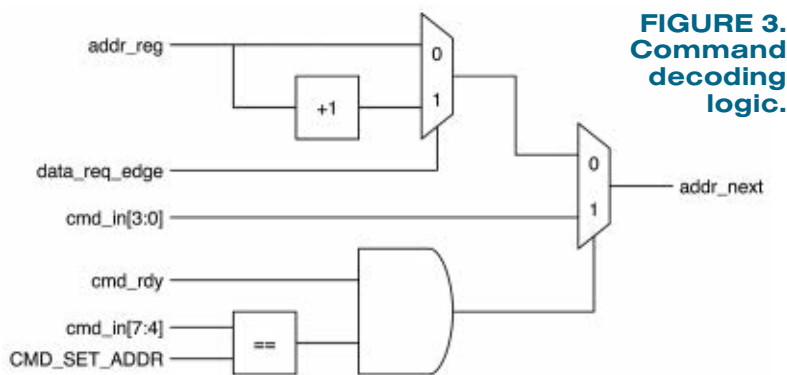
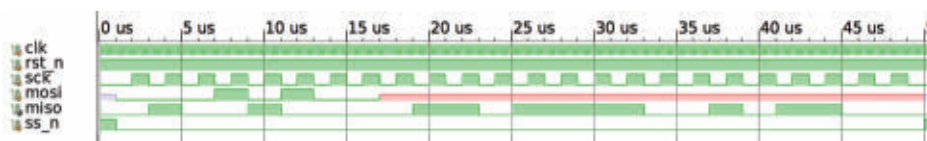


FIGURE 3.
Command
decoding
logic.



SCREENSHOT 1. SPI serial ROM test bench.

Let's Test!

With everything glued together, it's time to verify operation of the SPI serial ROM. I wrote a test bench (`spi_rom_tb.v`) which essentially "bit bangs" the SPI protocol at a 1 MHz SPI clock rate to test our module.

Two operations we need to test are the command decoding logic and the incrementing of the ROM read address for subsequent reads. The test sequence is as follows:

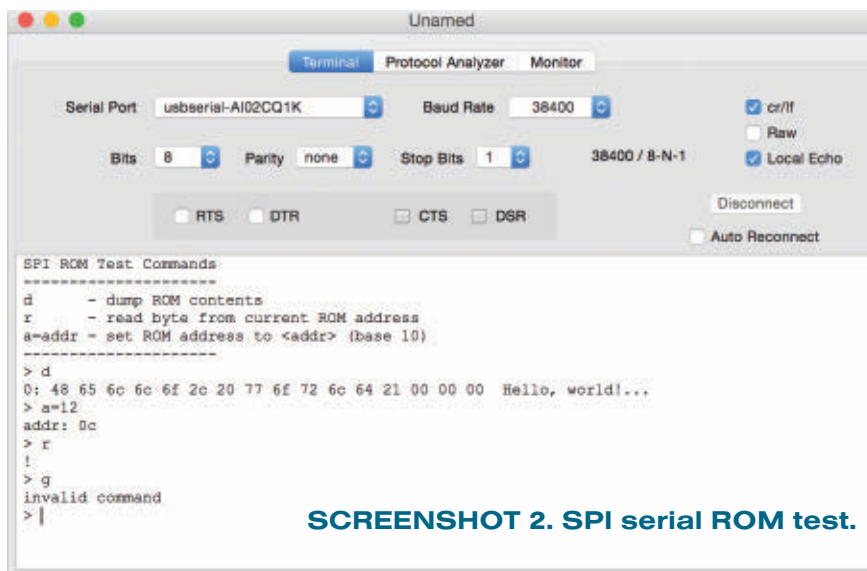
1. Initialize the SPI bus to an idle state.
2. Send a command to the SPI serial ROM to set the ROM read address to 0x4.
3. Read two bytes from the SPI serial ROM.

Let's take a look at **Screenshot 1** to verify our SPI serial ROM operation. Our module first receives the command 0x14 which sets the ROM read address to 0x4. At the same time, the SPI serial ROM is sending the ROM data from address 0x0 (the initial reset value for the ROM read address) to the SPI master. This data is the letter 'H,' or ASCII code 0x48.

Table 6.		
CONNECTION	MOJO V3 PIN	MICROSTICK II PIN
SCK	93	18
MOSI	142	17
MISO	143	16
SS	144	3
Ground	GND	27

The next two read operations output data from addresses 0x4 and 0x5, which are 'o' and ',' (ASCII comes 0x6F and 0x2C). Everything works as advertised!

Let's get this loaded on the Mojo V3 and test it with our Microstick II.



SCREENSHOT 2. SPI serial ROM test.

Hardware Time

The code for the PIC24FJ64GB002 on the Microstick II and the Mojo V3 is available for download at the article link. I soldered a right-angle header to J6 of the Microstick II, which connects to pins 21 and 22 for use with the UART module. You will need a 3.3V TTL serial cable to interface with your computer. I used a SparkFun FTDI

cable (DEV-09717) and the SerialTools software (available from the Apple App Store) for my testing. Connect the Mojo V3 and Microstick II per **Table 6**.

The test software is simple to use. It accepts three commands:

d — Dump ROM contents to screen.

r — Read byte from current ROM *read* address.

a=addr — Set ROM *read* address to <addr>; a base-10 number from 0-15.

You can see from **Screenshot 2** that everything works as expected.

Where Do We Go from Here?

The OpenCores website has many different cores available, as we discussed at the beginning of the article. One neat feature to explore is the Wishbone Bus. This is an open source bus architecture specifically designed to facilitate communication between IP cores on an FPGA for SoC design. Many of the cores on the site use the Wishbone Bus. Take a look around and find something to hack with.

Until next time, I hope you continue to enjoy the interesting, albeit complex world of FPGAs!

NV

Resources

OpenCores.org SPI Master/Slave Interface

http://opencores.org/project_spi_master_slaveEmbedded

Micro Mojo V3

<https://embeddedmicro.com/mojo-v3.html> Microchip

Microstick II

www.microchip.com/DevelopmentTools/ProductDetails.aspx?PartNO=DM330013-2SparkFun 3.3V

FTDI Cable

www.sparkfun.com/products/9717

SerialTools

<https://itunes.apple.com/us/app/serialtools/id611021963?mt=12> Wishbone

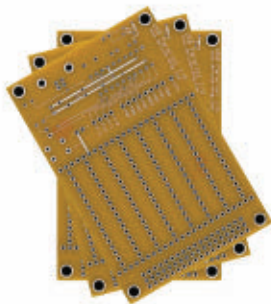
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http://opencores.org/opencores_wishbone

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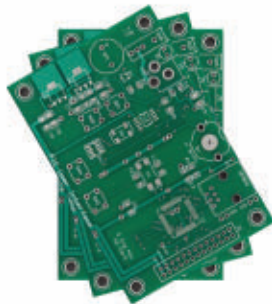


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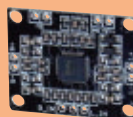
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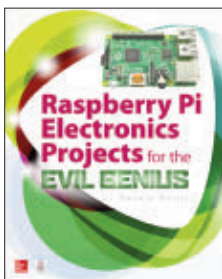
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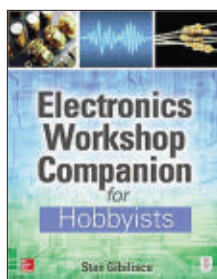
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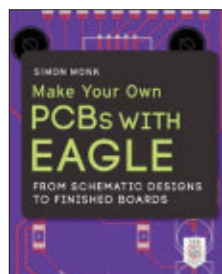
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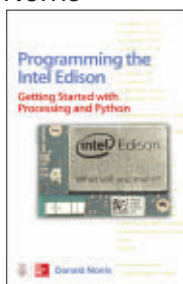


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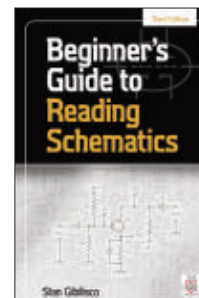
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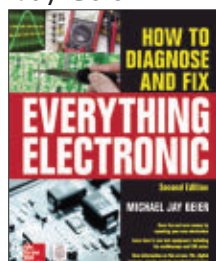


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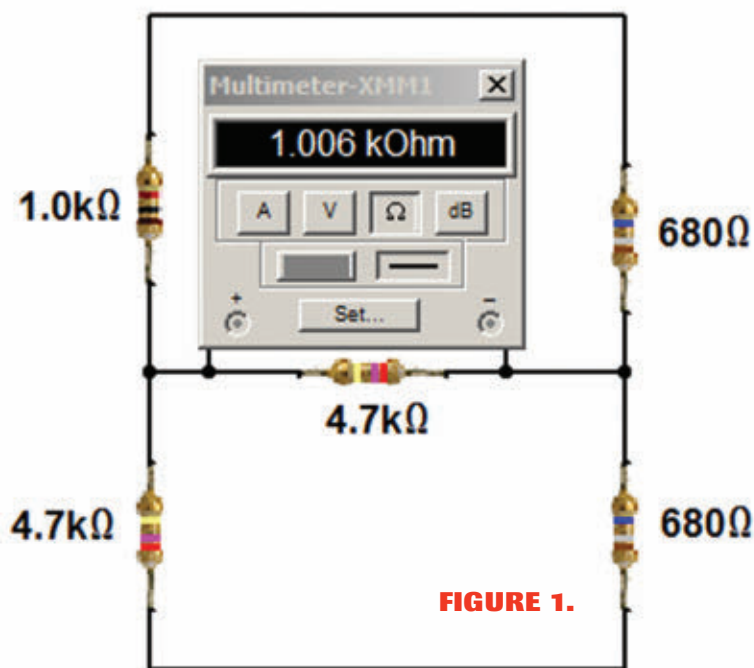


FIGURE 1.

Traditionally, a technician would lift one leg of a resistor to get an accurate resistance measurement. This can be difficult today since surface-mount components are often used. There is a technique taken from automatic test equipment called guarding that uses a controlled voltage source, ammeter, and strategically placed grounds to measure the current going through a single component. With a known source voltage and a current reading, the exact value of an individual resistor can be calculated.

Figure 2 shows how the resistance of the center resistor can be determined using a 1 V source and an ammeter. First, place the voltage source on one side of the resistor and the ammeter going to ground on the other

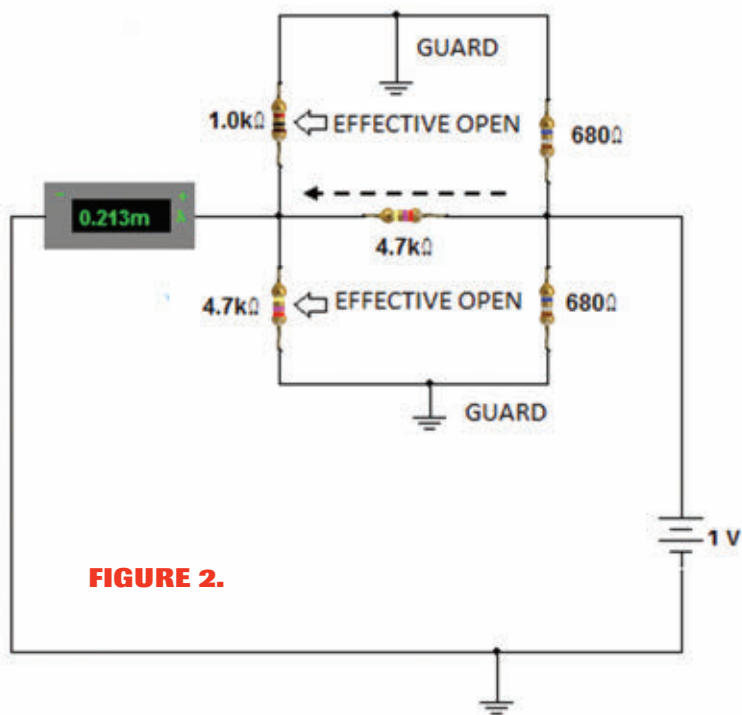


FIGURE 2.

Testing Techniques

By Richard Agard

Post comments on this article at
www.nutsvolts.com/magazine/article/July2016_In-Circuit-Testing-Techniques.

side. The difficulty now is the parallel paths around the resistor. To take these parallel paths out of the measurement, place a ground in the center of each path. With a ground on both sides of a resistor, there is no voltage drop across the resistor resulting in an effective open. The precise value of the resistor is calculated by dividing the source voltage by the current. In this case, 1V divided by .213 mA equals 4.7 k Ω .

The position of the source, ammeter, and grounds can be repositioned to measure any of the resistors without the need of breaking the circuit.

Figure 3 shows how the circuit can be reconfigured to measure the bottom left resistor. It is important to remember that just because the parallel paths are taken out of the measurement, doesn't mean that the parallel current paths are eliminated. Care must be taken not to damage any parallel components. It is recommended to use as low a voltage as is possible.

Now, it's time for a challenge to show how you would connect the circuit in **Figure 4** to accurately measure the other three resistors.

Find the answers on the next page ...

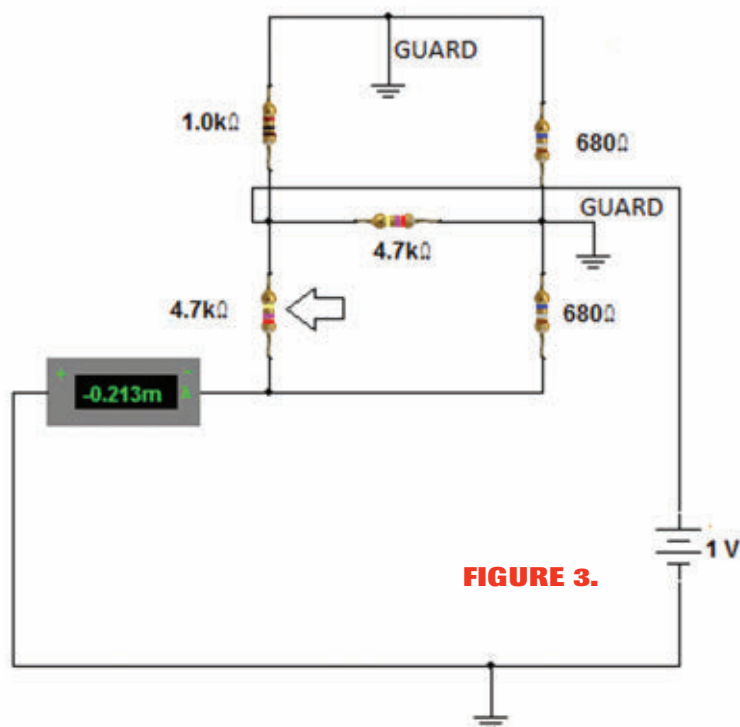


FIGURE 3.

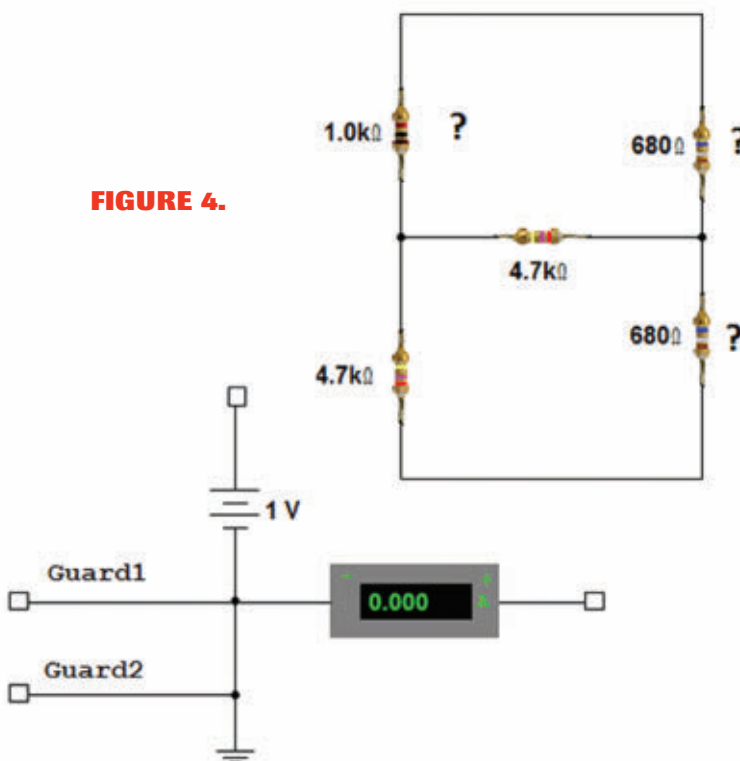
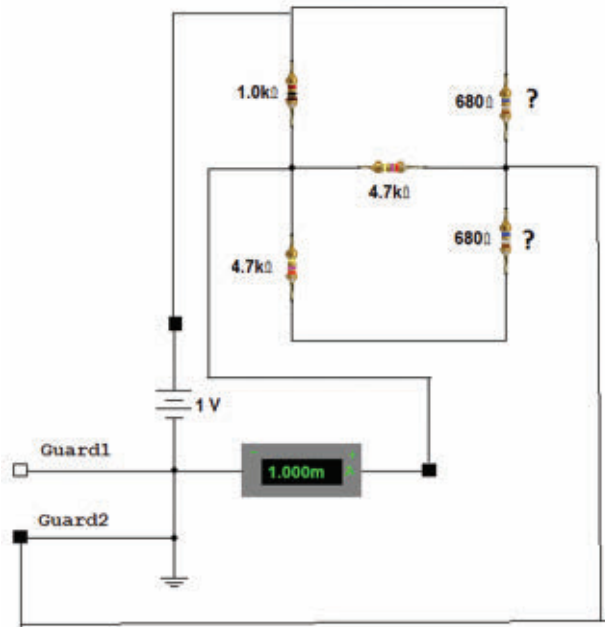
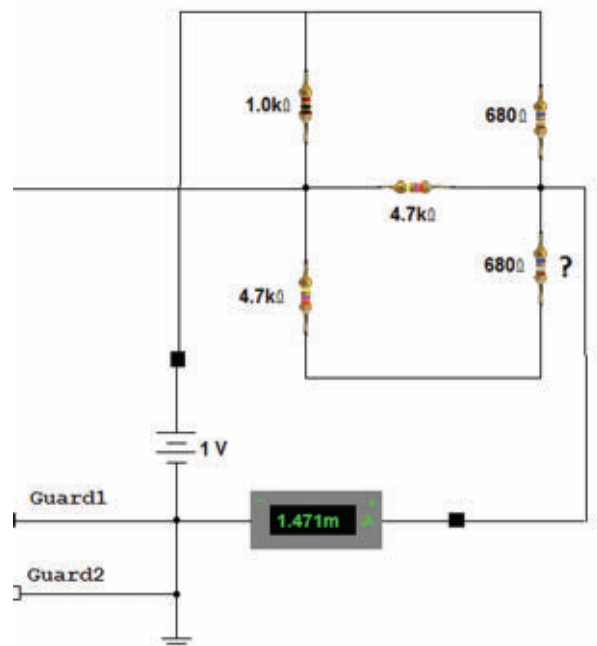


FIGURE 4.

ANSWER 1.



ANSWER 2.



Answers

Answer 1 (top left resistor)

To determine the top left resistor's value, place the voltage source on the top of the resistor and the ammeter going to ground on the bottom. This will insure a one volt drop across the resistor. Now, place the guard between the top right resistor and the bottom right resistor; this will prevent current flow through the center resistor and open

up the single parallel path around the test resistor. The value of the resistor can be determined by dividing the voltage by the measured current.

$$1 \text{ volt} / 1 \text{ mA} = 1,000\Omega$$

Answer 2 (top right resistor)

To determine the top right resistor's value, place the voltage source on the top of the resistor and the ammeter going to ground on the bottom. Now, place the guard between the top left resistor and the bottom left resistor; this will open up the single parallel path around the test resistor. The value of the resistor can be determined by dividing the voltage by the measured current.

$$1 \text{ volt} / 1.471 \text{ mA} = 680\Omega$$

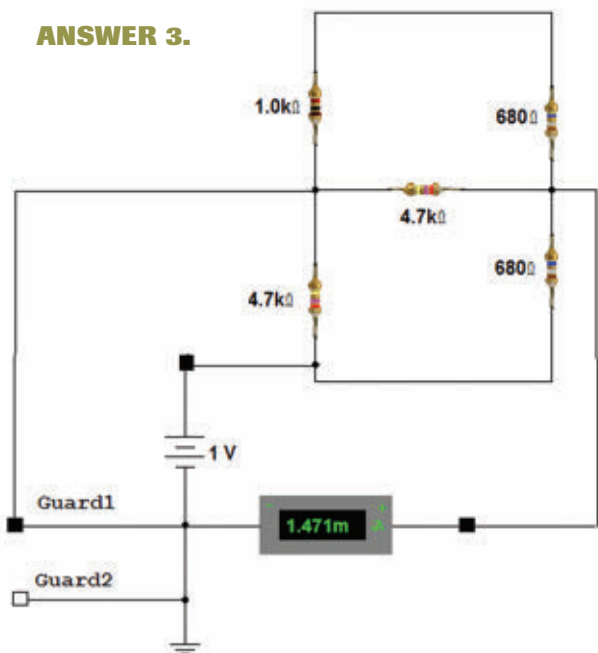
Answer 3 (bottom right resistor)

To determine the bottom right resistor's value, place the voltage source on the top of the resistor and the ammeter going to ground on the bottom. Now, place the guard between the top left resistor and the bottom left resistor; this will open up the single parallel path around the test resistor. The value of the resistor can be determined by dividing the voltage by the measured current.

$$1 \text{ volt} / 1.47 \text{ mA} = 680\Omega$$

So, did you pass? **NV**

ANSWER 3.



The Key to the Code

I've previously mentioned that my projects tend to be focused on entertainment, and a new wave of entertainment venues is sweeping the nation: escape rooms. Yes, people pay to have themselves locked into a series of rooms, which force them to use their intellect and problem-solving skills to defeat the puzzles and locks holding them prisoner. The first time I played, our team "escaped" with just five seconds left on the game clock. The experience was kind of exhilarating, and I understand why this trend — which has been popular in Asia for several years — has made its way to America.

I've had a 10 year professional relationship with the Halloween industry, and I'm finding that many of these business owners are turning to escape rooms to generate income for a facility that might otherwise be dormant for six to eight months of the year. These same people are now turning to me for different kinds of prop programs: puzzles and locks.

As you might imagine, I've been getting many requests for 12- and 16-key keypad entry codes, so I decided to create an embedded object that I could fold into my 1 ms background process (discussed in the May 2016 issue). Yes, I know, matrix keypads are not terribly sexy and exciting, and I would go so far as to place a bet that many young *Nuts & Volts* readers have never used a mechanical matrix keypad — though they've used simulations of these creatures on their smartphones.

I'm asking you to trust me, though. Matrix keypads are very useful for stand-alone embedded projects. Combine one with an LCD or other display, and the basis for many useful *practical* projects are at our disposal. Let's jump in. Even though this is old school, it's a whole lot of fun.

The goal this time out is to scan and debounce a 3x4 or 4x4

matrix keypad in the 1 ms background (i.e., separate cog) process. This process also takes care of a milliseconds timer and a couple LEDs (automated blinking). If you missed the May issue, you may want to find it as it goes into detail about the 1 ms background process and coding for it. I don't tend to need background ADC (analog-to-digital converter) readings, so I removed that feature from my program which gives us plenty of bandwidth to scan a keypad. After scanning/debouncing, I think it would be nice to buffer key-press events which allow the foreground time to do other things.

Let's review the keypad scanning process before we jump into the code. A 4x4 matrix is composed of four rows of four columns of normally-open buttons that will connect the associated row and column wires. This means we can read 16 buttons with just eight inputs — but we cannot do it all at once. What we must do, in fact, is activate one row while disabling the others, then read the column bits as a group. By completing four reads and aligning the associated column nibbles into a result variable, we have scanned the keypad.

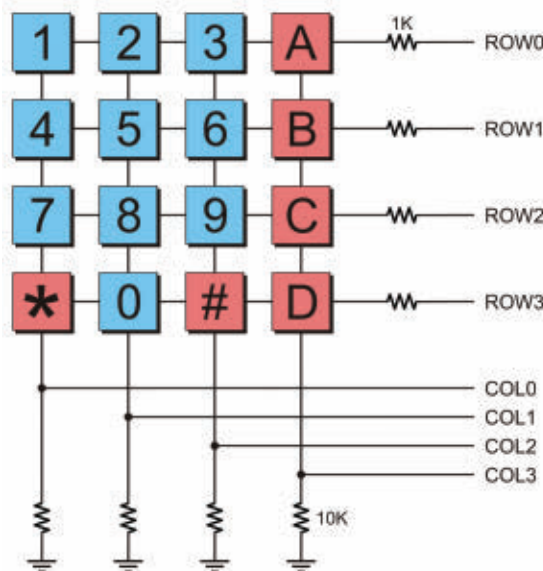
As with other buttons and switches, however, we shouldn't simply do this once and call it a day. In my code, I will not return a key scan as valid until I read the same input(s) through 25 consecutive cycles. As this code lives in my 1 ms background process, I can get a new key after 25 milliseconds, which is a reasonable debounce period.

Have a look at **Figure 1**; this is a simplified schematic of the matrix keypad connections. Note that the column lines are pulled down to ground; this is important — we don't want to leave these floating. The rows are attached

to the processor through 1K resistors. If you're careful, you can leave these out. I would suggest that it's prudent to have them until your code is fully vetted.

To scan a row, we will make its output line high while we make the others inputs. Again: *Disabled rows are inputs, not output-low*. With the one row selected, we read the column bits into the result variable. If the debounce requirement is met, the key is placed into a 16-key buffer. Note that when I use the term "key," it could, in fact, be multiple keys (a chord). We can use chords for special entries.

Let's look at the code. Remember, this gets called from



■ FIGURE 1. Keypad circuit.

the background process, hence runs every millisecond:

```
pri scan_keypad | row
    padwork := 0

    repeat row from 0 to 3
        outa[ROW0..ROW3] := |<row
        dira[ROW0..ROW3] := |<row
        padwork |= ina[COL3..COL0] {
            } << ((3-row) << 2)

    dira[ROW0..ROW3] := %0000

    if (padwork == padkey)
        if (++padcycles == KEY_MS)
            if (padkey)
                padbuf[phead++] := padkey
                phead &= %1111
            else
                if (padcycles == AUTO_KEY)
                    padbuf[phead++] := padkey
                    phead &= %1111
                    padcycles -= KEY_RATE
        else
            padkey := padwork
            padcycles := 1
```

We start by clearing the result variable *padwork*; this is required because the column scans will be OR'd into it with the loop code that follows. Note that a bit mask is created from the row number which gets copied to the OUTA and DIRA register so that just one of those pins is an output and high, while the others are set to input mode.

With a row activated, the column bits are read, shifted based on the row, then OR'd into *padwork*. With the column bits read, we can turn off the rows.

If the current scan (in *padwork*) matches the last scan (in *padkey*), the debounce cycles count is updated and compared to **KEY_MS**. If this matches, then *padkey* is moved into a circular buffer. The buffer ensures that a busy foreground process doesn't miss a key. When *padwork* differs from *padkey*, the debounce process is restarted.

Looking more closely at the code, you'll see there is a comparison to another constant called **AUTO_KEY**. For fun, I thought it would be nice to enable an auto repeat function when a key is held down. When the value of *padcycles* matches **AUTO_KEY**, another copy of the key is moved into the buffer. **AUTO_KEY** sets the delay for the auto repeat function; **KEY_RATE** determines how quickly keys repeat once that process starts.

If, for example, we want a key to start repeating after a one second press, then repeat every quarter second until the key is released, we would set **AUTO_KEY** to 1000 and **KEY_RATE** to 250. I disable the auto repeat function by setting **AUTO_KEY** to a negative value.

Now that we can buffer keys from a keypad, we need a way to read them from the foreground code.

Here's a simple method that does that:

```
pub read_keypad
    if (ptail <> phead)
        result := padbuf[ptail++]
        ptail &= %1111
    else
        result := 0
```

If the head and tail pointers for the buffer are different, there are one or more keys in the buffer. If a key is present, it will be returned as a 16-bit mask. Due to the layout of the rows and columns on a standard 4x4 pad, the keys will appear in the mask like this:

D#0*C987B654A321

The program contains a table of key mask constants which are used in this method to convert a mask to an ASCII code for the key:

```
pub key_to_ascii(kmask)

case kmask
    KEY_1 : return "1"
    KEY_2 : return "2"
    KEY_3 : return "3"
    KEY_4 : return "4"
    KEY_5 : return "5"
    KEY_6 : return "6"
    KEY_7 : return "7"
    KEY_8 : return "8"
    KEY_9 : return "9"
    KEY_0 : return "0"
    KEY_A : return "A"
    KEY_B : return "B"
    KEY_C : return "C"
    KEY_D : return "D"
    KEY_S : return "*"
    KEY_P : return "#"

return -1
```

If the mask passed to this routine is empty or has multiple keys pressed, it will return -1. For special cases, we can create multi-key (chord) masks and test for them directly (we'll see this shortly). The reason that we're returning valid single keys as ASCII characters is that this lets us adapt a lot of code that was written for terminal input; it also simplifies range checking by putting the numbers into a contiguous group of values. In projects looking for a specific sequence (e.g., a lock), we can collect the entries into a character array and treat them like a string, comparing them against a known unlock code.

In a real world project I coded for a friend, he asked that the keyboard be ignored during an error condition. Instead of complicating the key scan code, I added a routine to flush anything out of the keyboard buffer:

```
pub flush_keypad

    longfill(@padbuf, 0, 18)
```

Yes, it's that easy, but with a cautionary note: The

keypad buffer and head and tail pointers must all be longs and defined in a contiguous group.

Lock It Up!

Okay, then; we have a nice little buffered keypad, so let's turn it into something. How about a simple electronic lock? Easy peasy.

I prototyped the code on a Propeller Activity Board (PAB) using a 4x4 matrix keypad and four-character/14-segment display. Using the alpha-numeric display allows us to have a nicer user experience. For simpler projects, we could use seven-segment displays.

On boot-up, the display shows "LOCK" and the unlock output pin is low. In application, this would drive a FET or BJT to drive a solenoid lock. When a key is pressed, the screen is cleared and the current keys are displayed. When four digits are in the display, the code compares the user input to the embedded unlock code; if they match, the display changes to "OPEN" and the unlock output is driven high. Pressing any key will restore the lock state.

What if we want to change the lock code? No worries, we can do that, too; the process isn't obvious — for good reason — and does require knowledge of the current code, just like changing an online password. While developing my basic lock code, I originally had two entry methods: one that simply accepted the code; then another for entering and editing a new code. Once things were working, these methods were consolidated in `get_code()`:

```
pub get_code(edit) | len, key

    flush_keypad

    len := 0

    if (edit)
        bytefill(@keybuf, "*", 4)
    else
        bytefill(@keybuf, 0, 4)

    segs.str(@keybuf)

    repeat
        key := key_to_ascii(read_keypad)
        case key
            "0".. "9" :
                if (len < 4)
                    keybuf[len++] := key
                    segs.str(@keybuf)
                    if (edit == false)
                        if (len == 4)
                            return

            "*" :
                if (edit)
```

```
        if (len > 0)
            keybuf[-len] := "*"
            segs.str(@keybuf)
        else
            return 0

    "#" :
        if (edit)
            if ((len == 0) or (len == 4))
                return len
            else
                return 0

    "A".. "D" :
        ifnot (edit)
            return 0
```

This method takes a true/false parameter that tells the program if we're editing or just entering. In edit mode, an empty place in the display is filled with an asterisk — blank spaces are just blank in simple entry mode. The asterisks are there to remind the user the program is in edit mode. It's important to create a user experience that — if not obvious — requires only a single training session and is easy to remember.

At the beginning, the display is filled with the appropriate character(s) and drops into the entry loop. In either mode, pressing a digit key adds the digit to the display. In entry mode, four digits cause the method to exit with the new input in the array called `keybuf[]`. The Propeller doesn't have a string data type, but there are a couple methods that operate on an array of characters. The requirement for these arrays is to be null-terminated. For the four-digit lock, `keybuf[]` is an array of five bytes (four keys plus the null). The * and # keys are used in edit mode. If one or more keys for a new sequence have been entered, pressing * deletes the last entry. If a valid four-digit entry is in the display, pressing # accepts the new code and returns.

Okay, we have a method for entering or editing the code. Let's build a method for changing the current code. I'm following the trend of escape room props and forcing a special entry on power-up:

```
pub check_update | idx

    time.pause(KEY_MS << 1)

    if (read_keypad <> STAR_POUND)
        flush_keypad
        return

    segs.scroll_str(@CurrentCode, 250)
    get_code(false)
    ifnot (strcomp(@KeyCode, @keybuf))
        return

    segs.scroll_str(@NewCode, 250)

    if (get_code(true) == 4)
        bytemove(@KeyCode, @keybuf, 4)
        repeat idx from 0 to 3
            ee.wr_byte(@KeyCode[idx],
                KeyCode[idx])
```


The **check_update()** method is called immediately after program objects are set up. This means that we have to insert a delay at the top of the method to allow the background cog to debounce the keypad. After the delay, we check for the two-key combination of * and #. If this is not the case, the keypad buffer is flushed and we return.

If * and # are pressed on start-up, we scroll a message through the display asking for the current code. If this is correctly entered, another string is scrolled asking for the new code. If **get_code()** returns a valid code, it is copied to KeyCode (the lock code stored in a **DAT** table). KeyCode is then written to the EEPROM so that it is persistent between power/reset cycles. The pieces are in place, so let's look at the top of the program:

```

dat

    KeyCode      byte    "1234", 0

pub main

    setup

    check_update

    repeat
        segs.str(string("LOCK"))
        get_code(false)
        if !strcmp(@KeyCode, @keybuf))
            segs.str(string("OPEN"))
            io.high(LED_26)
            repeat until (read_keypad)
            flush_keypad
            io.low(LED_26)
        else
            time.pause(100)

```

The key code for our lock is stored as a string (an array of bytes) in a **DAT** section. By structuring as a string, we are able to use Spin's **strcmp()** function to determine if the code entered is a match. When that's the case, the display shows "OPEN."

This display update serves two purposes: It's confirmation, and it replaces the lock code so that others cannot see the code while the devices are open. Pressing any key on the pad returns us to the locked position.

Mind you, this program is designed for mechanisms that are in the locked state without power; devices like the Adafruit #1512 solenoid lock.

Warning: Do not connect any device with a solenoid directly to the Propeller; you must use a FET or BJT buffer.

Numeric Entry

Earlier, I pointed out that converting key presses as ASCII characters allows us to adopt a lot of code designed for terminals and other serial streams. Here's a method that demonstrates decimal entry using a 3x4 or 4x4 keypad.

As both versions have the * and # keys, we will use them as * for backspace; # for enter:

```

pub get_dec(flush) : value | key

    if (flush)
        flush_keypad

    repeat
        segs.dec(value)
        key := key_to_ascii(read_keypad)
        case key
            "0"... "9" :
                value *= 10
                value += (key - "0")

            "*" :
                value /= 10

            "#" :
                return

```

The method includes a parameter to flush the keypad before accepting the new entry; I like this because one never knows what's already in the buffer. We alias the result variable with the name value and drop into a loop that looks for keys, which are converted to their ASCII values.

Keys "0"... "9" cause the value to be shifted left to make room for the new ones digit. As this is decimal, shifting left is accomplished by multiplying the current value by 10.

Pressing the "*" divides the result by 10, removing the last input. Finally, pressing the "#" returns to the caller. Since we aliased the result variable with the name value, we don't have to specify it in the return line.

Okay, say it with me: Old school is still cool, and matrix keypads can be very useful in embedded projects.

I know that eight I/O pins seem like a lot, but that doesn't have to be the case. The HC-8+ uses shift registers for inputs, so I adapted this code to run on it.

Sharing the EEPROM Buss

The PAB doesn't expose the EEPROM buss, so I used other pins for the electronic lock display. The latest EFX-TEK HC-8+ buffers the EEPROM buss so that common displays and accessories can be connected without consuming other I/O pins. My friend that needed the keypad code sent along a multi-mode display that could handle serial, I²C, and SPI data streams. I connected it to the HC-8+ I²C buss, wrote a simple I²C driver for it, and went to work.

Everything was fine until I attempted to update the EEPROM — the IDE (integrated development environment)

Item	Source	BOM
Propeller Activity Board	Parallax #32910	
4x4 Matrix keypad	Parallax #27899	
1/4W 1K resistor	Mouser #291-1K-RC	
1/4W 10K resistor	Mouser #291-10K-RC	
I ² C Alpha/num display	Adafruit #1911	
M/M jumpers (w/o housing)	Pololu #1802	
M/F jumpers (w/o housing)	Pololu #1801	
4x1-pin housing	Pololu #1903	
1x1-pin housing	Pololu #1900	

complained that the EEPROM had failed. What?!

Let me just skip ahead of the brain gnashing and tell you what happened. When the Propeller connects to the EEPROM, the I²C buss speed is around 270 kHz (it's running from an RC clock during boot-up/reprogramming, so this will vary a bit). The multi-function display could only handle 100 kHz I²C. What I believe was happening is that the clock speed into the device was causing it to generate errant zeroes (pulling the SDA line low) which interfered with the EEPROM access. Of course, the same interference occurred during boot-up, as well.

Lesson: If you're going to share the EEPROM I²C buss, stick with I²C-only chips that can run at least 400 kHz (an I²C standard). This will prevent interference with programming and boot-up.

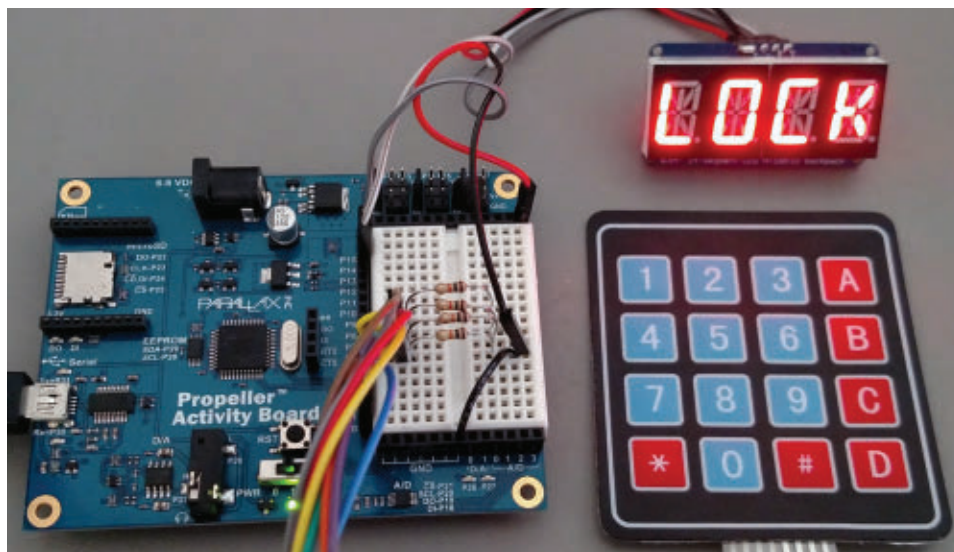
The display I connected to my lock program uses a HOLTEK HT16K33 segment driver. Consulting the datasheet, I found that it can handle an I²C buss speed of 400 kHz which is well above the speed of the Propeller's I²C clock during boot-up or reprogramming. And, yes, I have confirmed that it can share the Propeller EEPROM buss without any problems.

Getting Connected

I can't count the number of spools of 24-gauge solid wire I've purchased from All Electronics for prototyping on solderless breadboards. For short connections, this is still my preference, but for longer connections it's better to use stranded wire. The problem with stranded wire is that you cannot twist it and push it into a breadboard; it really needs to have a proper pin terminal.

I was happy to learn that Pololu is selling wires with male or female terminations without the normal single-pin housing. Of course, they also carry a very large array of single- and double-row housings which allow for the easy fabrication of custom cables. **Figure 2** shows my prototype setup of the e-lock using custom cables for the display and keypad assembled from Pololu wire components.


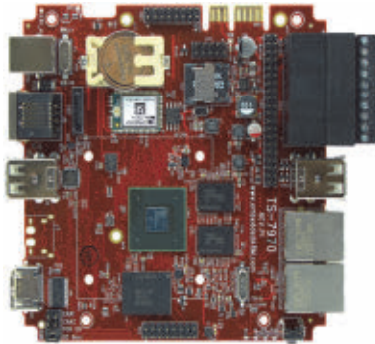

For the keypad, I made two six inch custom cables with male pins on both ends. This allows me to separate the rows and columns lines. For my I²C display, I used a four-pin female on the display end, with single-pin male headers for plugging into the breadboard. I've been recommending these wires to my friends building escape room props. The HC-8+ low voltage I/O is through 0.025 male header posts, and the variety of wire lengths and



■ FIGURE 2. E-lock prototype.

terminal housings available from Pololu make fabricating custom cables a breeze.

Code. Wires. Keep them neat and orderly, and things will go smoothly. Until next time, keep spinning and winning with the Propeller! **NV**







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A better and simpler solution, and one that I use on numerous vehicles that I have, is to use a Trickle Charger designed to be connected continuously. That type of charger uses a microcomputer to monitor battery state of charge and prevents overcharging and undercharging.

Some modern cars have low voltage disconnects but they typically disconnect too late and while retaining some charge in the battery, it is generally insufficient to start the vehicle.

John Benedict
via email

#2 You may use a relay that does not require constant power to maintain contact state. A “latching relay” is a generic term that is used

to describe a relay that maintains its contact position after the control power has been removed. You can control a circuit by simply providing a single pulse to the relay control circuit.

Latching relays are also desirable when you need to have a relay that maintains its position during an interruption of power.

There are three main types of latching relays: magnetic latching; mechanical latching; and impulse sequencing. Contact ratings vary with common ratings at 3 to 10A. If what you find can't handle your current, you can have it drive a slave high current contactor like the ones used in most vehicles.

John Sinks
Edelstein, IL

#3 Before recommending any high tech solution, have you located the electronics that caused the power drain? I recommend doing so by removing the power fuses of each circuit one by one until the drain disappears and measuring the current at the battery while removing each fuse. Then, analyze if that drain is some important part of the vehicle (such as radio/entertainment/clock) that may be on with the ignition off. That drain problem should be solved before using the LVD.

As for the LVD that you have now, I believe it is a timer based circuit. The relay current may now be acceptable or not needed after the drain problem is solved.

Raymond Ramirez
Bayamon, PR



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AnarenBack Cover
M.E. Labs38

EDUCATION

Cleveland Institute of Electronics..32

Command Productions15
M.E. Labs38
Poscope27

EMBEDDED SYSTEMS

Saelig Co. Inc.33
Technologic Systems63

ENCLOSURES

Front Panel Express LLC39

EVENTS

AUVSI65

LCDs/DISPLAYS

Saelig Co., Inc.33

MICROCONTROLLERS / I/O BOARDS

Ion Motion Control39
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MISC./SURPLUS

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MOTORS / MOTOR CONTROL

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RF TRANSMITTERS/RECEIVERS

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ROBOTICS

Cleveland Institute of Electronics..32
Electronix Express9
Hitec3
Robot Power23
Ion Motion Control39

TEST EQUIPMENT

Electronix Express9
Pico Technology67
Poscope27
Saelig Co., Inc.33
TEquipment63

TOOLS

PanaVise15
Poscope27
TEquipment2

WIRE, CABLE AND CONNECTORS

All Electronics Corp.53

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Technologic Systems63

All Electronics Corp.	53
AnarenBack Cover	
AP Circuits14	
AUVSI65	
CIE32	
Command Productions15	
Electronix Express9	
ExpressPCB52	
Front Panel Express LLC39	
Hitec3	
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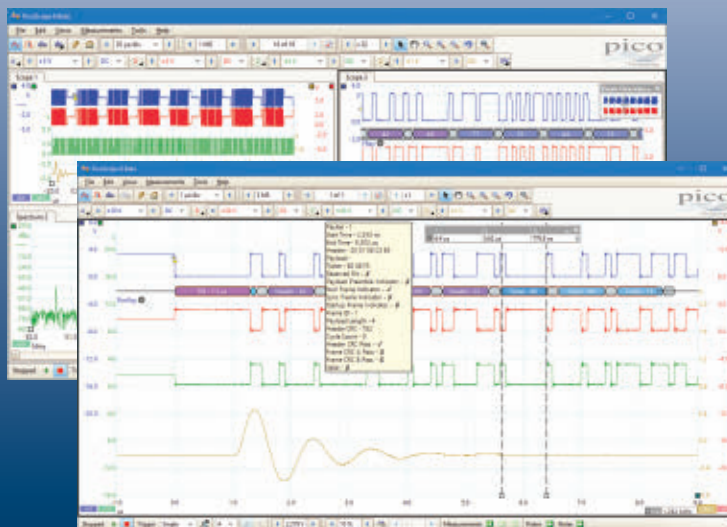
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